REPORT 1

A TECHNICAL AND ECONOMIC EVALUATION
OF
THERMAL SPALLATION DRILLING TECHNOLOGY

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For

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By

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TABLE OF CONTENTS

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VOLUME I

TECHNICAL AND ECONOMIC EVALUATION

ABSTRACT

Thermal spallation of rock may be defined as a type of progressive rock failure caused by the creation of thermal stresses induced by a sudden application of heat from a high temperature source. This technology is applicable to only certain types of hard rock, such as dolomite, taconite, and granite. In 1981 and 1982, the deepest holes ever drilled by this process were drilled in granite to depths of 1086 feet and 425 feet respectively. Penetration rates at the bottom of the deeper hole reached a maximum of 100 ft./hr. Because of these high rates, considerable interest was generated concerning the use of this technology for the drilling of deep holes. Based on this interest, this study was undertaken to evaluate the technical and economic aspects of the technology in general.

In recent years, this methodology has been developed primarily by the Linde Division of Union Carbide Corporation, Tonawands, New York; Browning Engineering Corporation, Hanover, New Hampshire; and Flame Jet Partners Limited, Encino, California. It has been used for blasthole drilling, the cutting of chambers at the bottom of drilled holes, and the cutting of narrow grooves in rock. However, because of the very high temperatures generated by the flame jet and the application of the technology to only certain types of rock, other areas of use have been very limited.

In this report, evaluation of the technology was performed by conceptually designing and costing a theoretical flame jet drilling rig. The design process reviews a number of different concepts of the various components needed, and then chooses those pieces of equipment that best suit the needs of the system and have the best chance of being properly developed. The final

concept consists of a flexible umbilical hose containing several internal hoses for carrying the various required fluids. An evaluation of this system was then made to determine its operational characteristics.

The drilling capabilities and the economics of this rig were then compared to a conventional rotary drilling rig by theoretically drilling two holes of approximately 15,000 feet in depth. This comparison was done by use of a spread sheet type computer program.

The results of this study indicate that flame jet drilling performs significantly better in both time and cost. These results are due primarily to the high penetration rates, the reduced number of trips, and the decreased trip time due to the use of the umbilical. However, this significant time and cost advantage must be tempered by the fact that they are based on the assumption that the main components of the flame jet rig can be realistically and reliably built. Unfortunately, the use of an umbilical system presents very realistic and difficult design problems as hole depth extends beyond 7000 feet. Thus, unless a significant market for the use of this equipment can be found, further development of an umbilical type system is very questionable.

An alternate system suggested by LASL may circumvent many of the problems stated above. This concept consists of using concentric pipes and a down hole fluid separation system. Concentric pipe built by the Walker-Neer Manufacturing Company, Wichita Falls, Texas, has been used successfully in the drilling industry for years. Fluid separators have also been developed and used. Although this concept will also present problems, it may be worth investigating.

I. PURPOSE AND METHODOLOGY OF THE STUDY

Thermal spallation drilling is a unique technology that involves the application of heat against the face of certain types of rock so as to make a hole in the rock. Recent utilization of this method to drill several holes in granite at high penetration rates and to depths of 1100 ft. and 400 ft. has caused increased interest in it. It is because of this interest and the lack of understanding of the potential of the technology that this study has been undertaken.

The primary purposes of the study are to technically and economically evaluate the use of thermal spallation in drilling, and to identify areas where it can be used. To accomplish these purposes, the following evaluation methodology has been developed.

1. Determine the state-of-the-art of thermal spallation technology.
2. Analyze the technology to determine how it can be used. Identify constraints and determine possible solutions.
3. Conceptually design a drilling rig that utilizes this concept. Identify and analyze design considerations and operational characteristics.
4. Develop a computer model that will technically and economically evaluate and compare the deep hole drilling advantages of this rig to those of a conventional rotary rig.
    a.) The model shall incorporate several generic well drilling programs that include all drilling activities and all time and cost factors.
    b.) The generic wells will be theoretically drilled by both the thermal spallation rig and a conventional rotary rig of similar depth rating.

c.) Cost and time factors, as well as other characteristics of interest, shall be compared and evaluated. Sensitivity analysis techniques will be used to determine key factors that affect these characteristics.

5. Based on the data obtained, a series of conclusions, noting both advantages and disadvantages of thermal spallation drilling technology, shall be drawn.

II. THE DEVELOPMENT OF THERMAL SPALLATION TECHNOLOGY

Thermal spallation of rock may be defined as a type of progressive rock failure caused by the creation of thermal stresses induced by a sudden application of heat from a high temperature source.[1] This method of failure provides a mechanism for breaking rock that has been in use, in one form or another, from ancient times until now. Only in recent years has serious technical evaluation been given to it. One of the first published studies on this subject was "A General Theory of Spalling," by F. H. Norton, Journal of American Ceramics, 1925. Other preliminary efforts to determine the value of this technology were conducted by Stoces[2] in the Zinnwald mines in Germany in 1927. In the early 1940's, the Linde Division of Union Carbide developed the jet piercing process used for drilling blast holes in taconite.

In recent years, considerable work has been done on this technology, including the establishment of a theoretical knowledge base and the design, development, and use of field equipment. Most of this work has been done in Russia, Canada, and the United States. Engineers in Germany, France, England, and South Africa have also contibuted significantly.

In the United States, most of the work has been done by three companies: The Linde Division of Union Carbide Corporation, Tanawanda, New York; Browning Engineering Corporation, Hanover, New Hampshire; and Flame Jet Partners, Limited, Encino, California. The systems developed by each of these companies relate specifically to the drilling of

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1. Thirumalai, K., Rock Mechanics - Theory and Practice, 1969, p. 705.

2. Stoces, B., The Application of the Firing Method in Modern Mining, Verlag Speidel und Wruzel, Akademisch-Polytechnische Buchhandlung, Zurich, 1927.

holes in rock. The combustion process used in each to create the high temperature source has significant differences. Other U. S. corporations that have seriously evaluated this technology and its equipment include Ingersoll-Rand (Canadian subsidiary), Bucyrus-Erie, and Hercules, Inc.

The U. S. Government has also contributed to the overall development of this technology. Agencies such as the Bureau of Mines, the Department of Defense, the Department of Transportation, and the Department of Energy have sponsored research projects that have investigated the theoretical processes invloved and have attempted to apply them to broader areas, such as rapid drilling of holes, tunneling, etc.

Normally, thermal spallation is used for the drilling of holes in very hard rock such as taconite, hematite, granite, etc. It is also used for channeling or cutting long grooves in granite. Lesser uses are found in the sculpturing and/or finishing of surfaces of hard rocks. It has also been used for drilling holes in ice.

III. THERMAL SPALLATION THEORY

As previously stated, thermal spallation is a type of progressive failure of rock caused by the creation of a thermal stress. The mechanism of failure is dependent upon efficient diffusion of thermal energy through the rock until the created thermal stress becomes great enough to exceed the ultimate shear or tensile strength of the rock.[3] Unfortunately, efficient diffusion of heat energy through rock is impeded by a number of factors, among which are the heterogeneous composition of the rock, its anisotropic properties, cracks, and fractures. In addition, the propagation of the stress appears to be limited by the presence of soft, elastic and/or fine grained minerals such as talc, chlorites, mica, sericites, and clays. These minerals tend to yield rather than expand upon heating, probably due to dehydration and thermal decomposition.[4] Considering these facts, the mechanisms of thermal spallation can be quite complex and can be developed in only certain types of rock.

Physically, spalls are flat, disc-like flakes of rock that range in size from several inches in diameter to small, grain size structures. The thickness of the flake is normally many times smaller than the diameter as noted in Figure 1. The physical dimensions of the spall are in part dependent upon the nature of the heating and the relative ability of the rock to spall.

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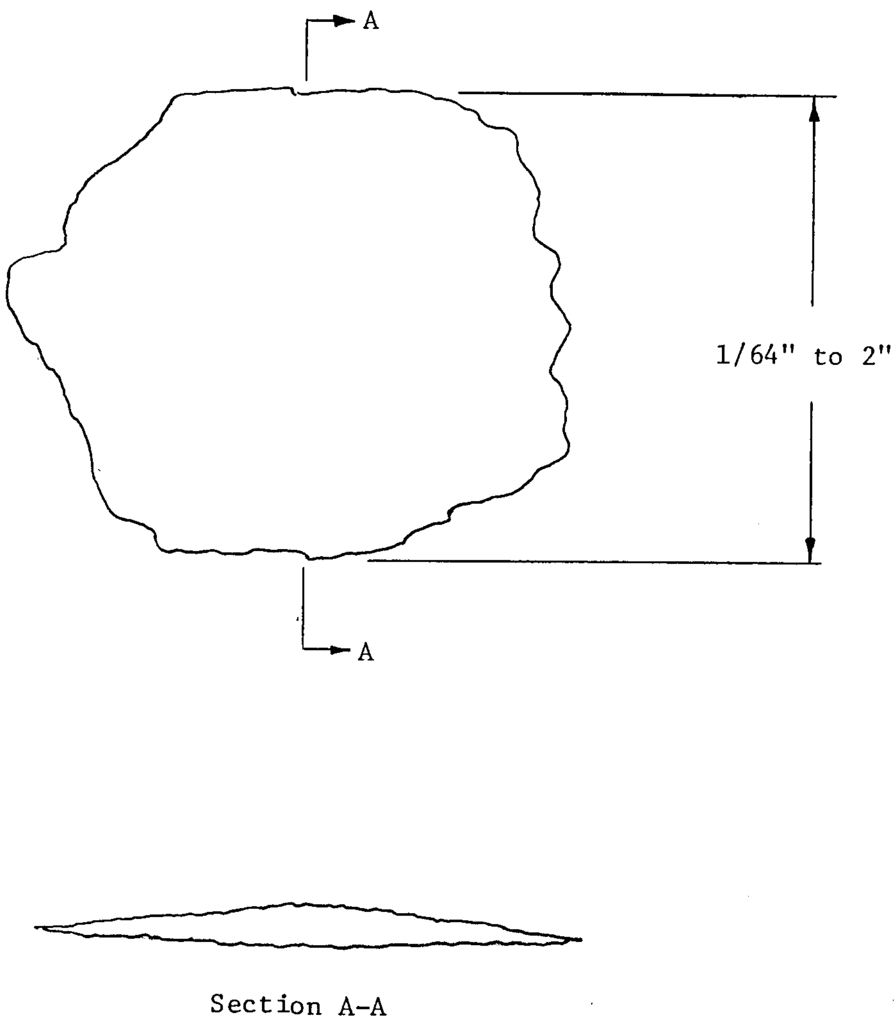
3. Freeman, D. C., Jr., Sawdye, J. A., and Mumpton, F. A., "The Mechanism of Thermal Spalling in Rocks," Quarterly of the Colorado School of Mines, 1963, p. 249.

4. *Ibid.*, p. 237.



NORMAL SPALL CONFIGURATION

Figure 1

Although the properties affecting the thermal spallability of rock are not well understood, a number of attempts have been made to develop formulas that can predict this phenomena. One formula[5] frequently cited in the literature is:

$$S = \frac{a \cdot e \cdot gr}{\sigma}$$

S = spallability
a = thermal diffusivity
e = percent thermal elongation
gr = grain size
σ = rock compressive strength

In this formula, thermal diffusivity, a, can be defined as the thermal conductivity divided by the product of the density and the specific heat.[6] Thermal diffusivity may be visualized as the rate of propagation of a thermal energy front in a body or as a measure of the heat absorbed during the migration of a thermal energy front as it moves through the body.

Numerous factors affect thermal diffusivity. Rock texture or spatial relationship of neighboring grains or crystals is important because heat conduction depends in an intricate way upon the arrangement of the molecules in a solid, and even more so upon the transfer of the kinetic energy of the electrons involved, as thermal energy is added to the system. The presence of interterrestrial voids or

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5. Geller, L. B., "A new Look at Thermal Rock Fracturing," Transactions of the Institute of Mining and Metallurgy, 1970, p. A153.

6. Calaman, J. J., and Rolseth, H. C., "Technical Advances Expand Use of Jet-Piercing Process in Taconite Industry," Int. Symp. on Mining Research, Univ. of Missouri, 1962.

cracks tends to impede this movement. The presence of fine grained or soft materials such as mica, clays, and talcs also tends to have this same effect.

Thermal elongation, e, refers to the actual linear expansion of a body during the application of thermal energy. It is measured in percent elongation and is significant because the difference of rates of thermal expansion, caused by differences of thermal energy levels in a rock structure, create high compressive stresses, which in turn cause mechanical failure. The temperatures at which these expansion rates occur is important because they influence the temperature levels at which spalling occurs.

Grain size, gr, appears to be important because of its relationship to the transfer of stresses. This factor is influenced by the texture or arrangement of the constituent grains in the body. In addition, when larger grains are separated by fine grained material, as opposed to being contiguous, they tend to dissipate thermal stresses.

Rock compressive strength, σ, is significant because it is the property of the rock that must be overcome if, in fact, failure is to occur. The combined effect of thermal diffusivity and elongation is greatly influenced by the level of the rock compression strength.

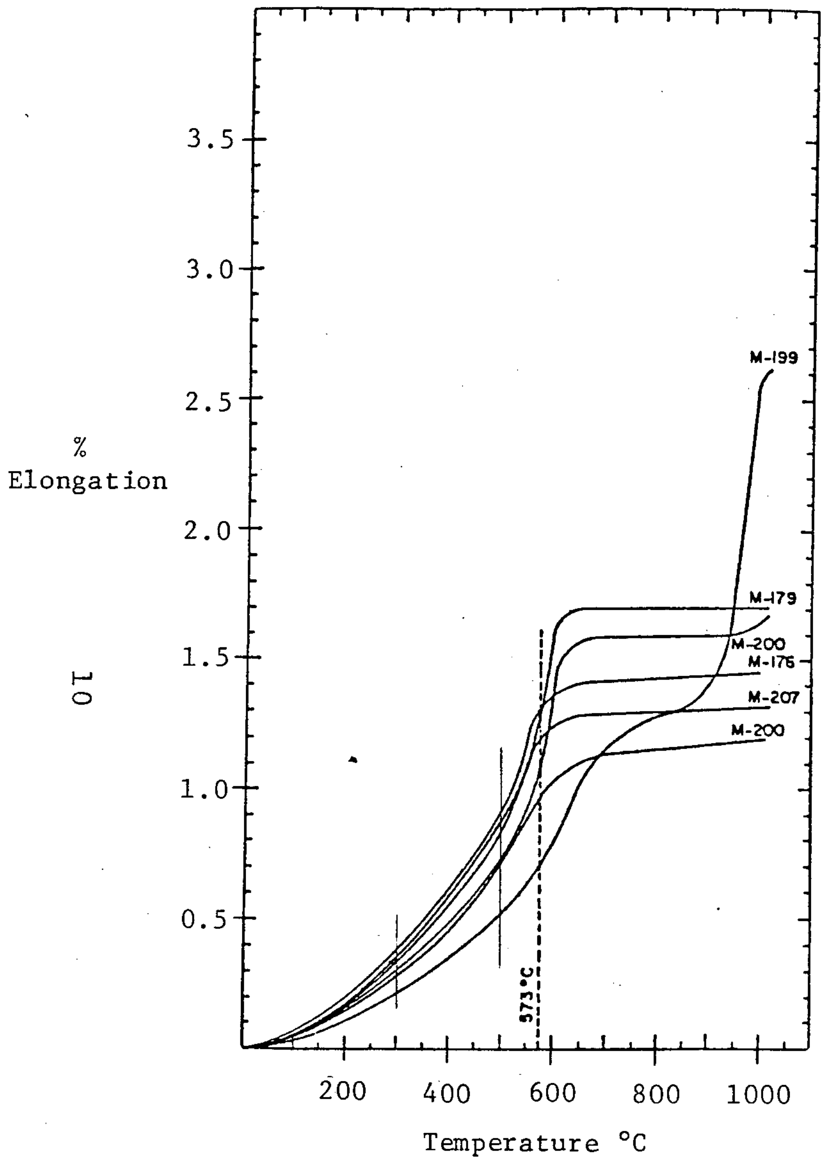
Variations of this formula have been developed and tested. None have proven to be successful with regard to the development of a reliable spallability index.

The development of an index is difficult due to the heterogeneous and anisotropic properties of rock. Within a given class of rock, such as taconite or shale, properties can vary radically from one section to another. Thus, the reactive characteristics of one piece to a given thermal flux can vary significantly from another piece at the same flux level. Further, the data within any given set of information must all be taken at the same temperature level, regardless of what that level is. In the past, this has not been universally accepted, and may in part lead to some of the confusion that exists. Figures 2 and 3 relate percent thermal elongation to ambient temperature of some of the rock samples of Table 1. Between 300°C and 500°C these elongations are fairly linear with a large factor of incremental change. From approximately 570°C and up, the percent elongations vary significantly and radically with no real sense of order. Thus, all data within a given set must be taken at the same temperature level if meaningful analysis of the data is to be made. Unfortunately, very little data that meets this criteria is available. Because of these types of difficulties, plus the limited amount of true scientific understanding of the problem, a spallability index has not as yet been developed.

An evaluation of a number of different rocks with regard to the development of such an index is noted in Table 1. This work was done by L. B. Geller of the Mining Research Center, Mines Branch, Department of Energy, Mines and Research, Ottawa, Canada. Geller attempted to correlate this data with little success. Two sets of correlated data are noted in Figures 4 and 5. No significant relationship can be noted.

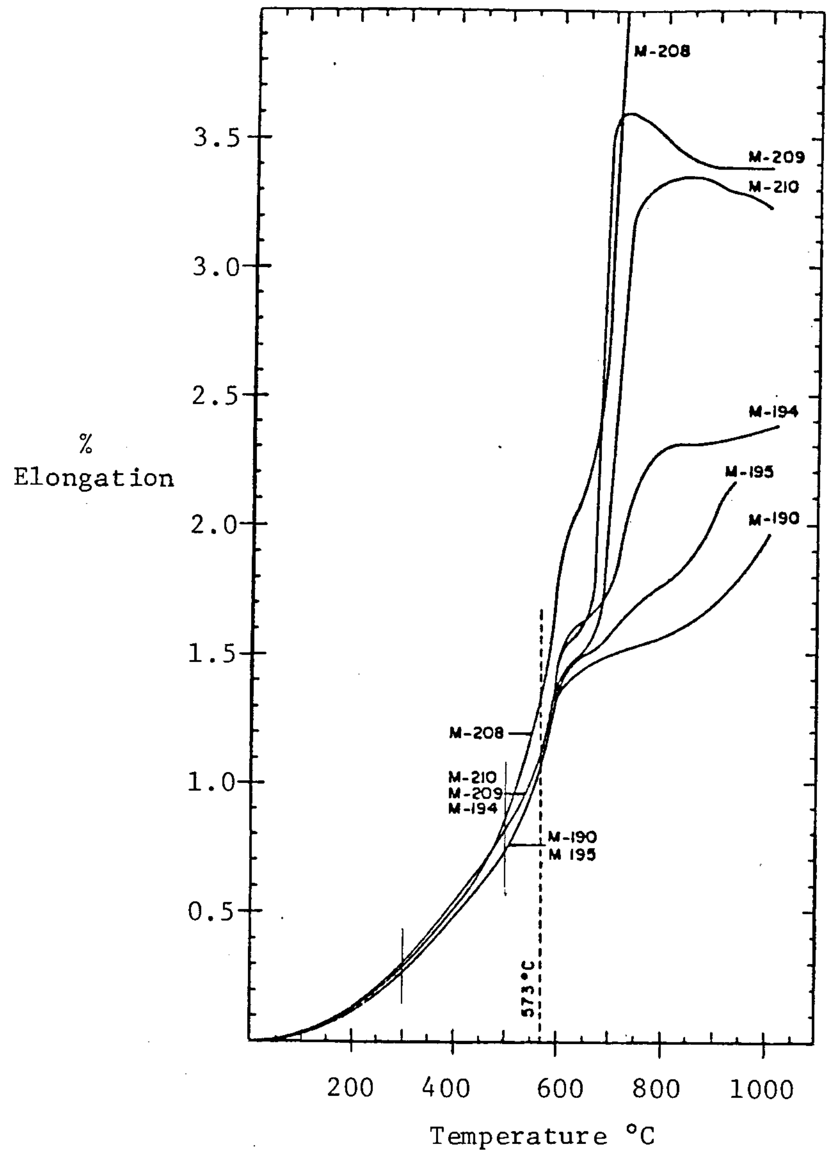
Figure 4 attempts to relate the product of thermal diffusivity and percent elongation at similar temperature levels to average rock penetration rates. No correlation is noted.

Figure 5 attempts to relate the spallability index number, S, noted above, to average rock penetration rates. Again, correlation is very questionable.



Average linear expansion of miscellaneous metamorphic and sedimentary rocks listed in Table 1.*

Figure 2



Average linear expansion of quartz-rich crystalline igneous rocks listed in Table 1.*

Figure 3

*Ref.: IR62-27, Department of Energy, Mines and Resources, Ottawa, Canada, 1962.

PHYSICAL CHARACTERISTICS OF ROCK SAMPLES

TABLE

Specimen Number	Rock Classification	Penetration Rate	Thermal Diffusivity a			Elongation e			Rock Texture	Compressive Failure Strength σ				Spallability s		
		(Avg.)	$10^{-4}cm^2/sec$			%				$10^3kg/cm^2$				$10^{-7}cm^3/(sec\ kg)$		
		Ft/hr	°C			°C				°C				°C		
			200	300	400	200	300	400		Amb.	200	300	400	200	300	400
Igneous Rocks																
M-188	Nepheline-syenite	21.32	74.6	69.0	64.8	.18	.38	.60	M	2.24	1.99	1.86	1.74	2.0	4.2	6.7
M-190	Rhyolite	20.01	99.5	90.0	81.5	.13	.38	.48	F							
M-209	Granite	18.04	95.5	86.4	78.5	.15	.31	.51	M							
M-194	Granite	18.04	83.6	78.5	75.0	.14	.31	.53	M							
M-210	Quartz-Manzonite	15.09	85.0	76.5	70.0	.15	.30	.50	C							
M-208	Granodiorite	14.10	76.5	70.5	65.2	.12	.26	.47	M							
M-195	Albite-Granite	11.48							M	1.52	1.44	1.40	1.36			
M-192	Nordmarkite	10.50	81.1	77.0	74.0	.14	.30	.47	C							
M-191	Hornblende-syenite	10.17	70.4	67.6	65.0	.14	.28	.45	M	1.88	1.72	1.63	1.56	1.7	3.5	5.6
M-193	Anorthosite	8.86	67.6	65.6	64.5	.10	.17	.30	C	1.68	1.65	1.63	1.62	4.1	6.9	12.0
M-178	Gabbro (diabase)	8.53	75.0	71.9	68.4	.10	.20	.30	M	3.50	3.35	3.26	3.19	0.7	1.3	1.9
M-189	Basalt	7.54				.10	.19	.29	F							
Quartzose Rocks																
M-179	Quartz	26.24	157.0	127.0	102.5	.17	.35	.57	C.C.							
M-176	Sandstone	22.63				.19	.37	.60	F							
M-207	Quartzite	21.98	143.8	124.0	106.5	.18	.34	.55	F	3.96	3.90	3.89	3.87	0.3	0.5	0.8
M-200	Taconite	12.46	115.0	102.0	90.0	.15	.29	.47	M							
M-199	Hornblende-quartz-gneiss	10.82	90.0	86.0	76.1	.10	.21	.35	M							
Carbonate Rocks																
M-168	Dolostone (recryst)	24.60	138.0	121.8	105.5	.22	.43	.66	C.C.							
M-186	Dolostone	24.60	87.5	71.8	67.0	.18	.36	.58	M	1.13	1.02	0.96	0.91	4.7	8.1	12.8
M-187	Dolomitic limestone	10.50	77.5	70.3	62.9	.23	.46	.71	F							
M-185	Limestone (recryst)	Nil	83.2	77.1	71.4	.09	.18	.30	C.C.							
M-184	Limestone (fine grain)	Nil	85.0	76.9	67.5	.09	.20	.34	F	1.97	1.90	1.86	1.82	0.2	0.4	0.6

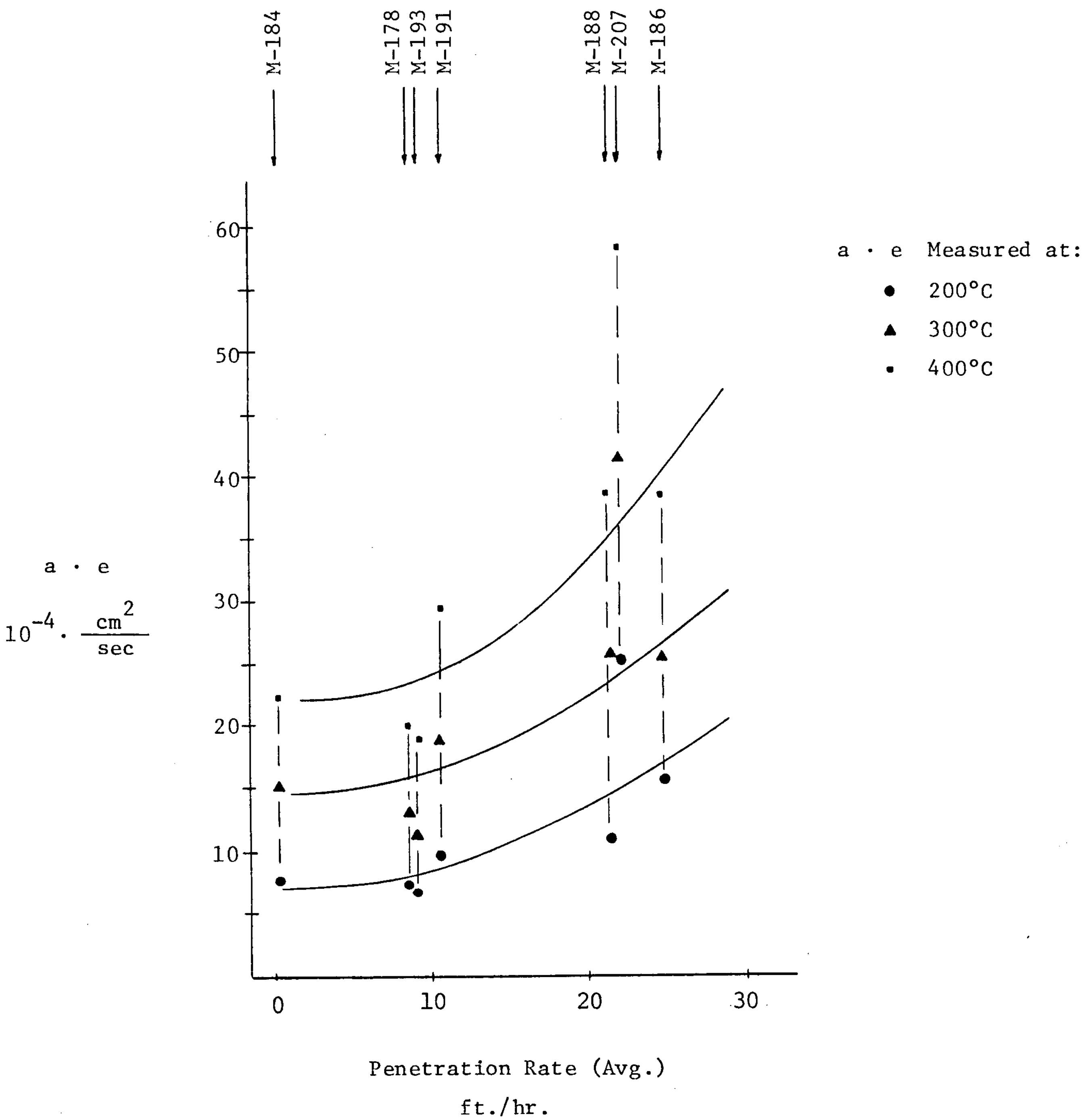

M-184
M-178
M-193
M-191
M-188
M-207
M-186
a · e Measured at:
200°C
300°C
400°C
a · e
$10^{-4} \cdot \frac{cm^2}{sec}$
10
20
30
40
50
60
0
10
20
30
Penetration Rate (Avg.)
ft./hr.

Figure 4

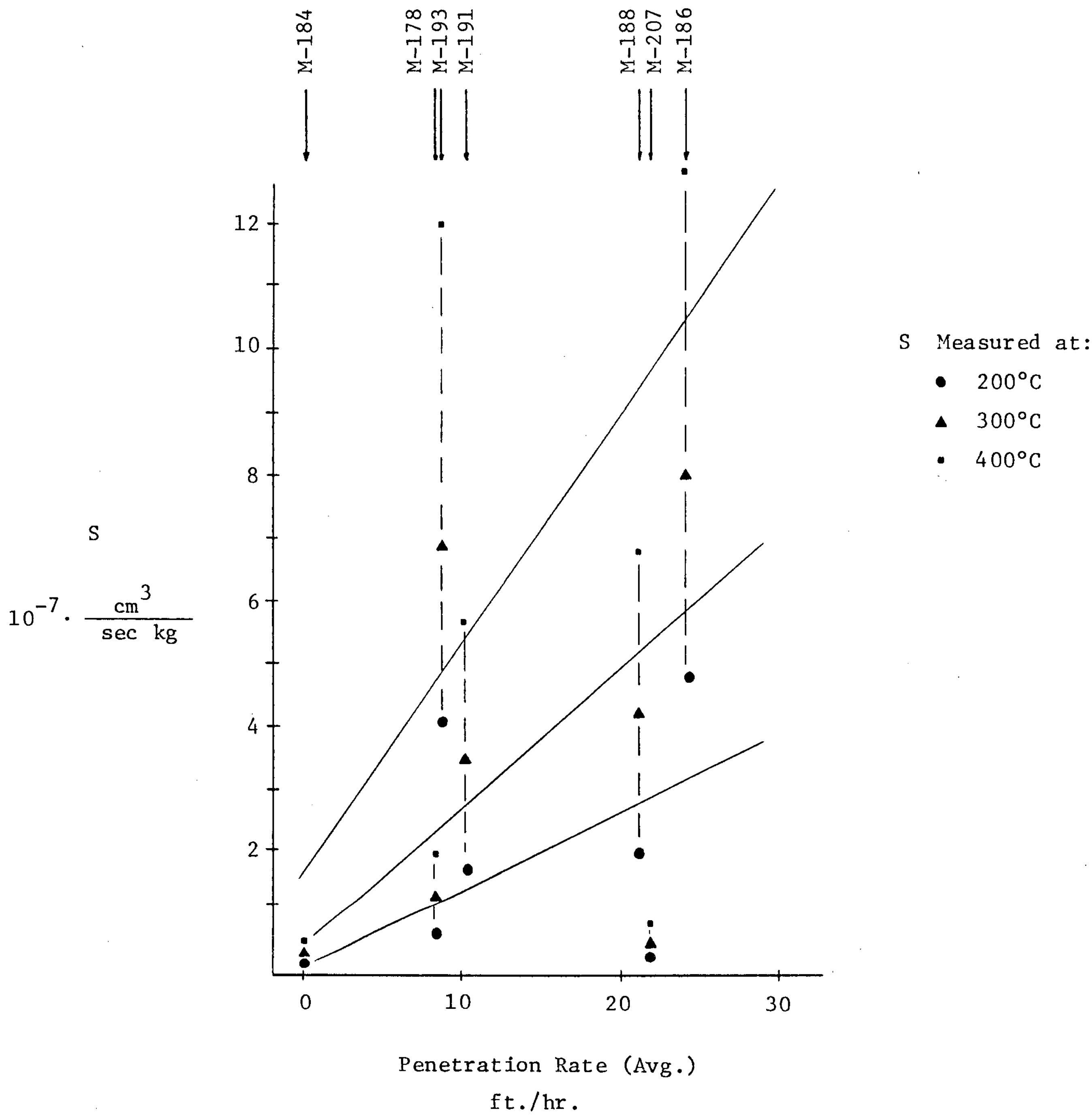

M-184
M-178
M-193
M-191
M-188
M-207
M-186
12
10
8
6
4
2
0
10
20
30
S
$10^{-7} \cdot \frac{cm^3}{sec\ kg}$
Penetration Rate (Avg.)
ft./hr.
S Measured at:
200°C
300°C
400°C

Figure 5

Because spallation is caused by thermal stress, change in thermal energy and therefore temperature change in the body is fundamental to the process. The relationship of temperature change and the development of thermal stress failure is important to understand. W. M. Gray notes that "risk of failure may be produced by reducing the heat flux associated with shock, or assuming constant strength of material, by increasing the thermal diffusivity. A body may be subjected to large increases in temperature (without severe stress problems) provided that differences in temperature between its parts are controlled. Thus, severity of thermal shock is associated not with the temperature of the body, but with the temperature gradients in it. In addition, the occurrence of failure depends solely on whether the surface temperature reaches the value associated with the critical (internal) stress and not upon the rate of heating. This means that the temperature gradients in the heated layers are not an indication of the stresses existing there."[7]

Temperature, T, rise in a body is noted by the graphs in Figure 6. There, curves represent temperature rise at various depths, Z, in a body, for given levels of heat flux, A, and at various time intervals, t, after the start of heating. These curves assume that the heat source is constant, thereby providing a constant heat flux (constant energy inflow, heat, per unit of time per unit area) over the entire surface of the body.

Assuming the above to be correct, Gray then assumed that temperature distribution during spallation is as noted in Figure 7. In this process he postulated that ". . . when the

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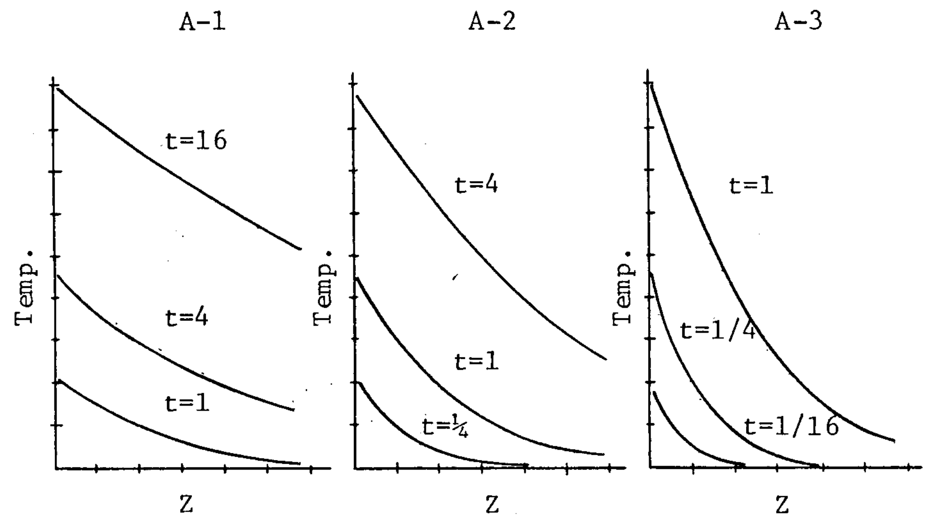
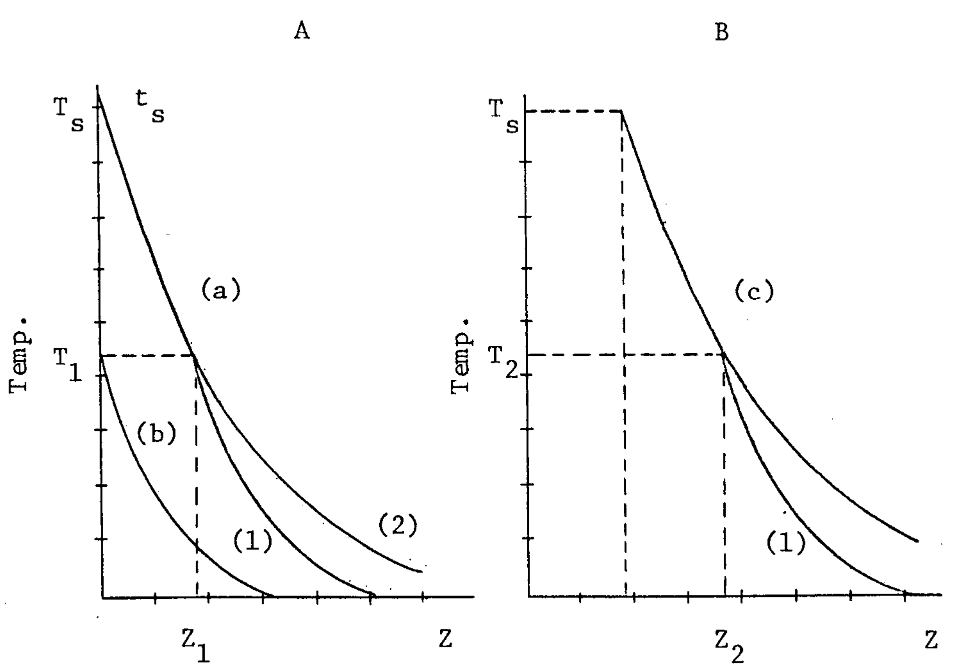
7. Gray, W. M. "Surface Spalling by Thermal Stresses in Rocks." Rock Mechanics Symposium, Toronto University, Toronto, Canada, 1965.



TEMPERATURE RISE IN A SOLID BEFORE SPALLING*

Figure 6



TEMPERATURE DISTRIBUTION DURING SPALLING*

Figure 7

* Ref.: Gray, W. M., "Surface Spalling by Thermal Stresses in Rocks," Rock Mechanics Symposium, Toronto University, Toronto, Canada, 1965.

surface reaches a critical temperature, a thin layer is removed simultaneously from the entire surface of the solid. When the first layer is removed a fresh surface at a lower temperature is exposed and the heat flux (assumed constant) is applied to it. A new heating cycle commences, differing slightly from the first cycle . . . because of a different temperature distribution in the solid." Figure 7 represents these changes. In graph A, curve (a) represents temperature distribution in a solid at time t_s after heating starts and when the first spall occurs. Spall thickness is assumed to be equal to thickness Z_1. Section Z_1 of curve (a) represents the temperature gradient below the spall. Curve (b) was the temperature gradient in the original solid at the time temperature T_s was reached (temperature T_1 being equal to the temperature below the surface that created the thermal stress required to crack or spall the rock). Section (1) of curve (a) represents curve (b) shifted over to illustrate the differences in the rock temperature for the second spalling cycle, as compared to the first.

Graph B illustrates the increased temperature gradient in the body after the second spall at depth Z_2 is created. Curve (c) represents this heat gradient curve. Again, an increase in heat content is noted, but it is proportionately less than the increase for the first spall. In due time, this temperature increase will reach a level of equilibrium.

Qualitative work performed by Geller indicates surface temperature, T_s, to be in the range of 200°C to 350°C when spalling takes place. This would indicate that the spalling process is a relatively low temperature operation. This temperature is considerably below the average melting range, 1000°C to 1200°C, of rock. These temperatures are also below the phase change of quartz which undergoes its alpha to beta transition at approximately 573°C, as noted in

Figure 2. Thus, the contention of most people that high quartz content indicates high spallability in a rock is still questionable although there does appear to be some correlation to overall quartz content.

Another point of interest is the lack of relationship between water and gas content of rock and spalling. One would assume that the expansion of these elements generated by the rise in temperature of the rock would create stress and therefore cause cracking and/or spalling. As yet, no correlation has been found.

IV. USE OF THERMAL SPALLATION TECHNOLOGY

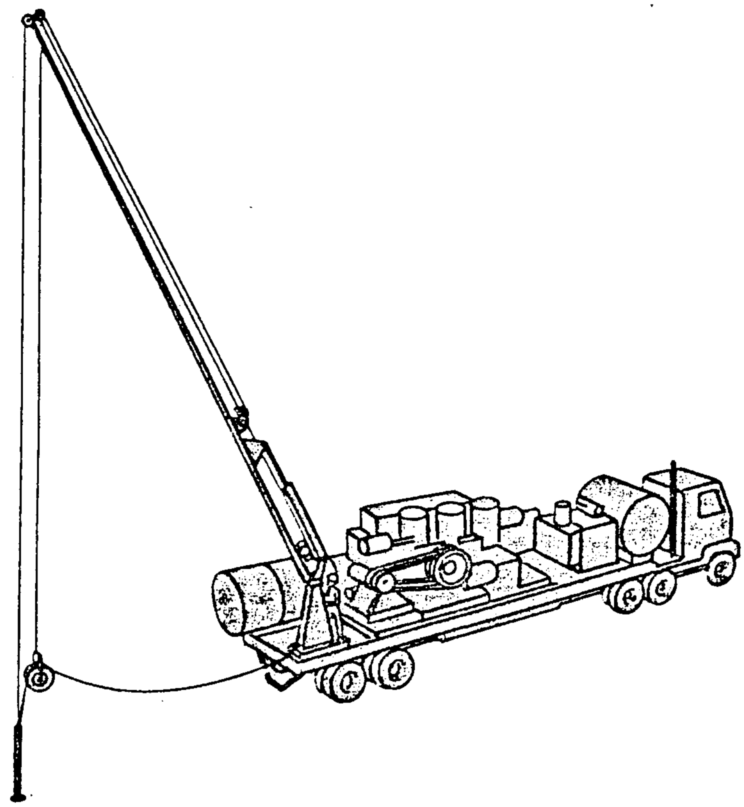
Flame jet drilling is used primarily for the drilling of blastholes, and for the channeling or cutting of rock. It is also used for smoothing rock surfaces and for configuring rock into statues.

Blasthole drilling is the process of drilling a specially configured hole into the earth. A blasting charge such as dynamite is placed into the hole and then detonated so as to shatter large segments of rock. In very hard rock such as taconite, it is more economical to drill these holes with flame jet systems. Truck mounted rigs, Figure 8, are normally used for this purpose.

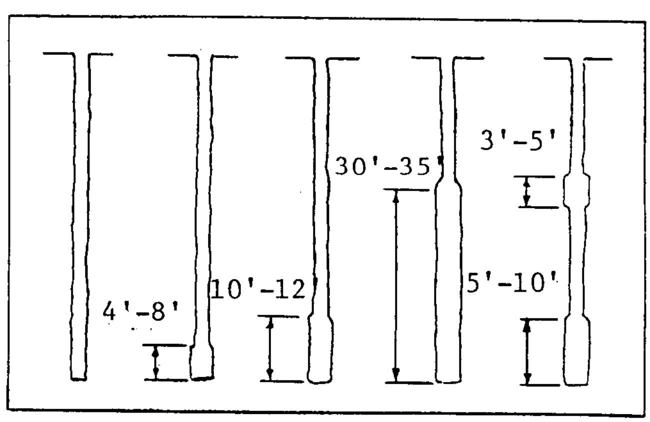
Blastholes are configured as noted in Figure 8. The enlarged areas or chambers at the bottom of these holes are a unique feature that can only be produced by a flame jet system. Although most of these holes are 40 to 50 feet in depth, many have been drilled to over 200 feet in depth.

Channeling is a process for cutting narrow grooves in rock. This process is normally used to cut out large blocks of rock in quarries without breaking or fracturing the rock. Channeling is usually done with a hand held flame jet tool as noted in Figure 9. Channels can range in size from 3½" to 6" in width and up to 25 feet in depth. This process is presently used throughout the world, where applicable.

In the U. S., two companies produce nearly all of the blasthole drilling rigs and channelers. They are the Linde Division of Union Carbide and Browning Engineering, Inc. A third company, Flame Jet Partners, Ltd., has developed and field tested an experimental rig. A review of these companies and their equipment follows.

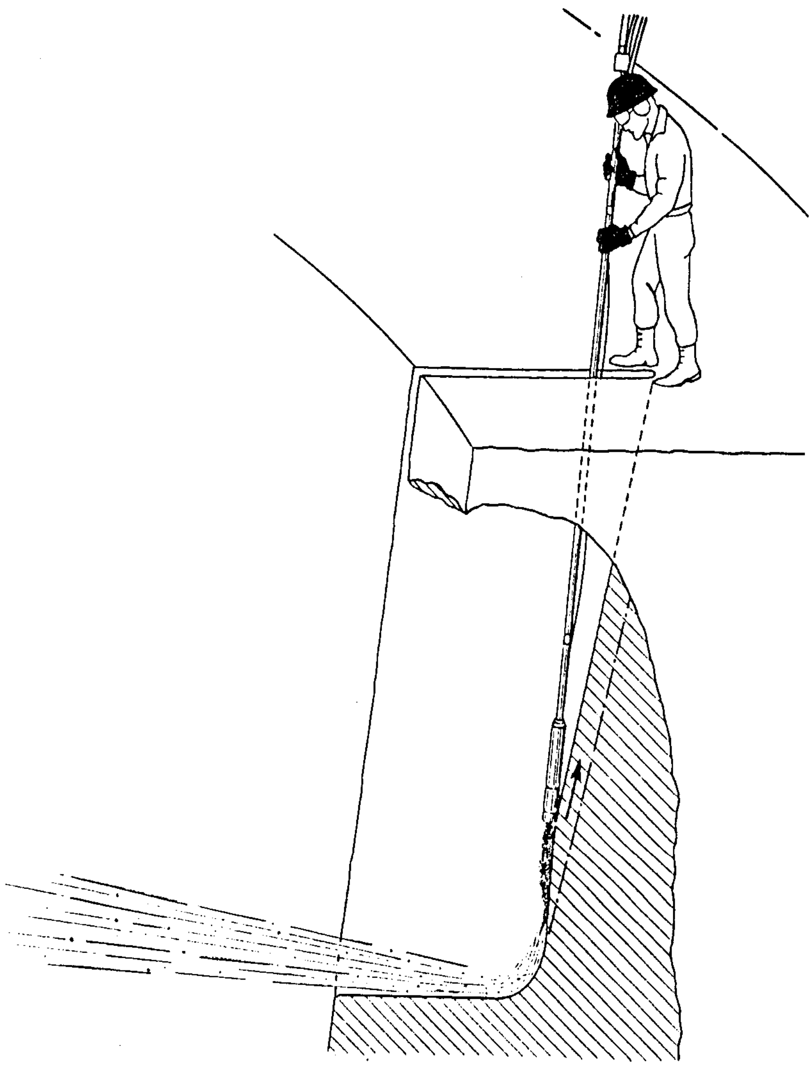


TRUCK MOUNTED BLASTHOLE RIG
FLAME JET CONFIGURATION



FLAME JET SHAPED BLASTHOLE CONFIGURATIONS
(TYPICAL)

Figure 8



HAND-HELD CHANNELING TOOL
IN OPERATION

Figure 9

A. Browning Engineering, Inc., Hanover, New Hampshire

1. Background

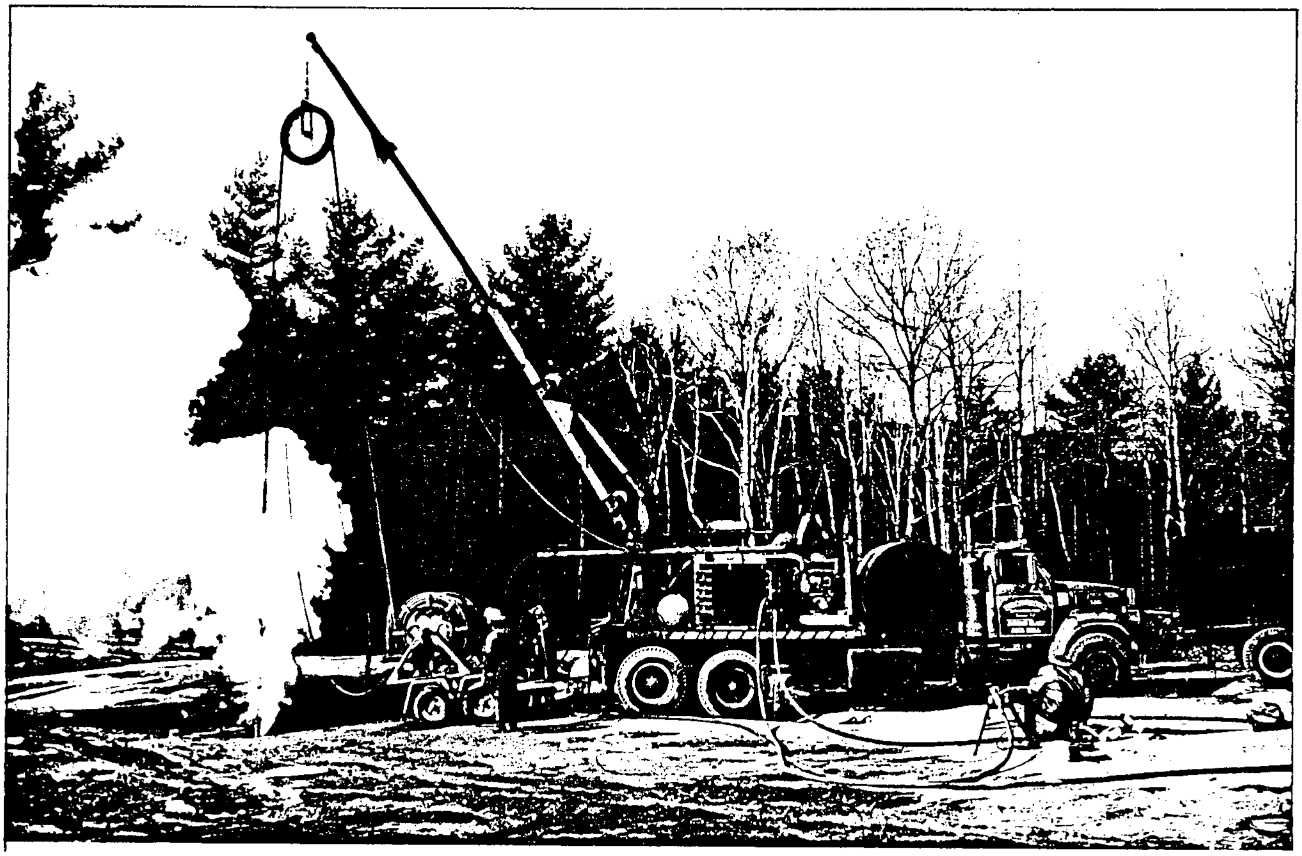
Browning Engineering is a privately owned company founded in 1961 by James A. Browning. The company is primarily devoted to the development and manufacture of flame jet equipment. In addition, the company designs and develops flame spraying systems.

In 1966 the company sold its first product, a hand held channeling tool used for cutting granite. Since then, more than 400 of these devices have been sold worldwide. In the mid-70's Browing developed a flame jet drilling system capable of drilling deep holes and/or chambering systems that could be used for blasting purposes. This system, Figure 10, is truck mounted and capable of drilling holes in granite to depths of 1000 ft or more. Browning Engineering has also used this technology to drill holes to depths of 1400 feet in the Antarctic ice cap.

James A. Browning, founder of the company, holds more than forty patents. He has taught for more than seventeen years at the Thayer School of Engineering, Dartmouth College, New Hampshire.

2. Operational Status

As stated, the company has sold more than 400 channeling tools on a worldwide basis, of which approximately 250 are still in operation. The company is actively involved in the development of this technology. The company's truck mounted flame jet drilling system is not being operated at present.



BROWNING ENGINEERING THERMO-BLAST ™ SYSTEM
TRUCK MOUNTED FLAME JET DRILLING RIG

Ref.: Browning Engineering, Inc., Hanover, New Hampshire

Figure 10

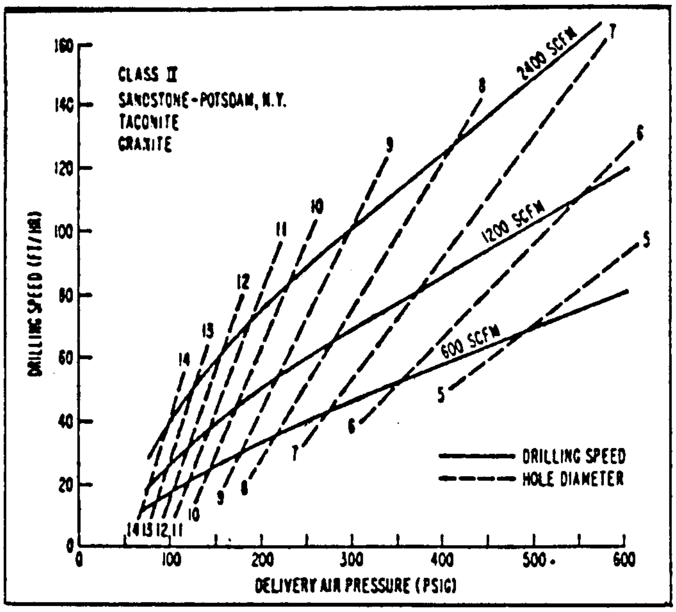
3. System Description

Browning's truck mounted flame jet drilling system operates on the principle of lowering into the ground a burner system attached to the lower end of a hose and cable arrangement. Combustion of a mixture of air and No. 2 fuel oil takes place within the burner and produces a flame jet of approximately 3300°F. When directed against certain types of rock, this jet will cause spalling to occur. Only the harder rock such as granite, guartzite, and dolomite are susceptible to this low temperature spalling type action.

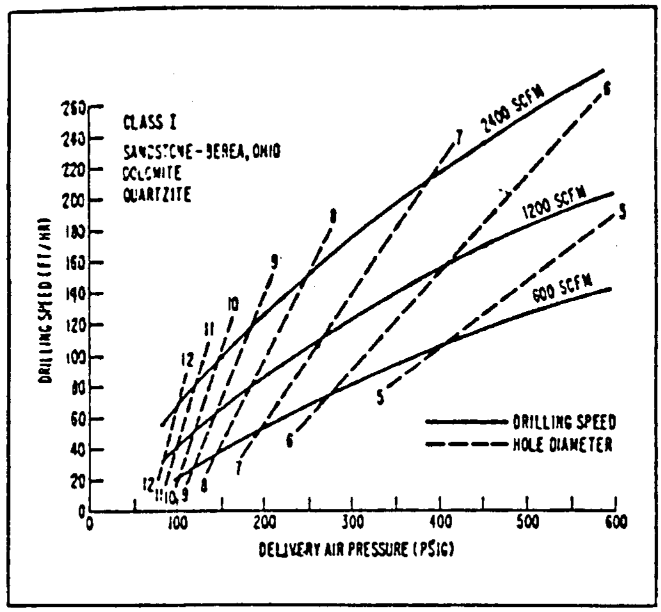
In this type of drilling operation, the volume of air delivered per unit of time, and its concurrent air pressure, is important to the combustion process and subsequently the rock penetration rate. Graphs showing this relationship for different types of rock are noted in Figure 11.

The burner, or combustor, is a relatively simple device made from steel tubing. It incorporates a single nozzle design and does not rotate. Although water is available in the system, none is used to water cool the combustion chamber. The burner is not designed for self-ignition and thus it must be lit by a torch prior to being lowered into the hole. Hard coating of the burner face is necessary to reduce erosion.

Water is used in the system to quench the walls of the hole, to reduce dust and noise, and to cool the escaping exhaust gases to a temperature that will allow the rubber supply hoses attached to the burner to be lowered safely into the hole. The water jets are



Granular Rock
Grain by Grain Removal



Heat-Spallable Rock
Spallation Removal

BROWNING ENGINEERING THERMO-BLAST™ SYSTEM

RELATIONSHIP OF AIR VOLUME & AIR PRESSURE TO PENETRATION RATE

Figure 11

normally placed several feet behind the burner to ensure that the water doesn't interfere with the exhaust flame and thereby create a cooling action on it.

The system has been used to drill numerous wells of various depths. The two most significant wells are described in Table 2. They are the deepest wells ever drilled by the flame jet process.

4. Future Plans

Although Browning is active in the sales of channeling tools, it presently has no plans to continue the development of the truck mounted flame jet hole drilling system until industry decides to make more use of this concept. At present, most of the taconite quarries which use this type of equipment are shut down. The use of chambering (the enlargement of sections of a hole) for applications other than blasthole drilling has not been aggressively pursued by industry.

5. System Evaluation

Browning's flame jet is a low operating cost system capable of effectively spalling hard rock. When properly used, it is a good system. The system has proven its ability to drill to 1000 feet in granite.

BROWNING ENGINEERING

DEEP WELL PROGRAMS

Table 2

	Coleman Quarry Conway, N. Hampshire	Rock of Ages Quarry Barre, Vermont
• Date	August, 1981	October, 1982
• Type of Rock	Competent Hard Granite	Competent Hard Granite
• Hole Diameter:		
Maximum	20.0 in. (1)	25.0 in.
Minimum	7.5 in.	10.0 in.
Average	10.5 in.	15.6 in.
• Hole Depth	1086 ft.	425 ft.
• Penetration Rates:		
Maximum	100 ft./hr.	30 ft./hr.
Minimum	20 ft./hr.	13 ft./hr.
Average	52 ft./hr.	—
• Down Hole Burner System:		
Type	Single Nozzle, Non-Rotating	Single Nozzle, Non-Rotating
Diameter	4.0 in.	5.5 in.
Length	20.0 ft.	29.5 ft.
• Water System:		
Surface Pump Flow Rate	20 gpm	—
Surface Pump Output Press.	200 psi	284 psi
Down Hole Nozzle Press.	30 psi (2)	—
• Fuel System:		
Fuel Type	#2 Fuel Oil	#2 Fuel Oil
Surface Pump Flow Rate	40 gph	40 gph
Surface Pump Output Press.	—	1200 psi
• Air System:		
Surface Equip. Flow Rate	1200 SCFM (3)	1200 SCFM (4)
Surface Equip. Output Press.	700 psi	300 psi
Down Hole Press. to Burner	550 psi	125 psi
• Flame Temp. (est.)	3300°F	3300°F
• Flame Velocity (est.)	5200 ft./sec.	5200 ft./sec.
• Exhaust Gas Exit Velocity at Surface (average)	2788 ft./min.	900 ft./min.

Notes:

(1) At bottom of hole, diameter increased to 40 inches.

(2) A 3/8 in. orifice was placed in the water line to reduce water flow. Excessive water flow tends to reduce the drilling rate because of its cooling effect.

(3) Two 900 SCFM, 350 psi compressors were feeding into a 1200 SCFM, 700 psi pressure booster.

(4) Two 600 SCFM, 300 psi compressors were used.

B. Linde Division, Union Carbide Corporation, Tonawanda, New York

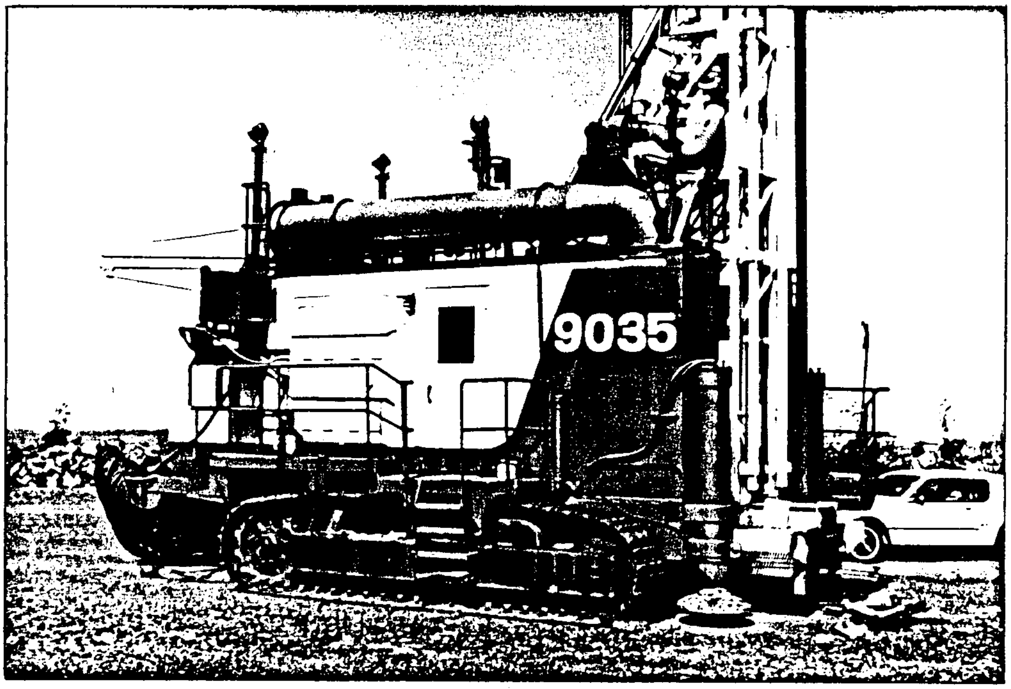
1. Background

Linde has been actively involved in the design, development, and field operation of jet piercing equipment since the late 1930's. Because of this, it can be considered the primary developer of this equipment in this country. To pursue this technology, Linde established a research facility in Minnesota that concentrated on the design of jet burners and their related effects on drilling rock. Linde also used its design engineering facilities in Tonawanda, New York to design the necessary drilling rigs and associated equipment. The combined efforts of both of these facilities has produced a number of patents and a line of equipment that has been readily accepted by industry.

2. Operational Status

Linde specializes in the design of jet piercing tools and rigs, Figure 12, that are used for the drilling and chambering of blastholes. Linde has built 42 rigs since the 1940's. Together the rigs have drilled more than 40 million feet of hole. Most of this drilling has been in taconite quarries. At present, most of these rigs are shut down because of lack of work in the quarries.

Linde has also developed a line of channeling tools for cutting hard rock. The company has sold approximately 200 of these tools.



LINDE JET PIERCING RIG MODEL JPM-5

Ref.: Linde Division, Union Carbide Corporation, Tonawanda, New York

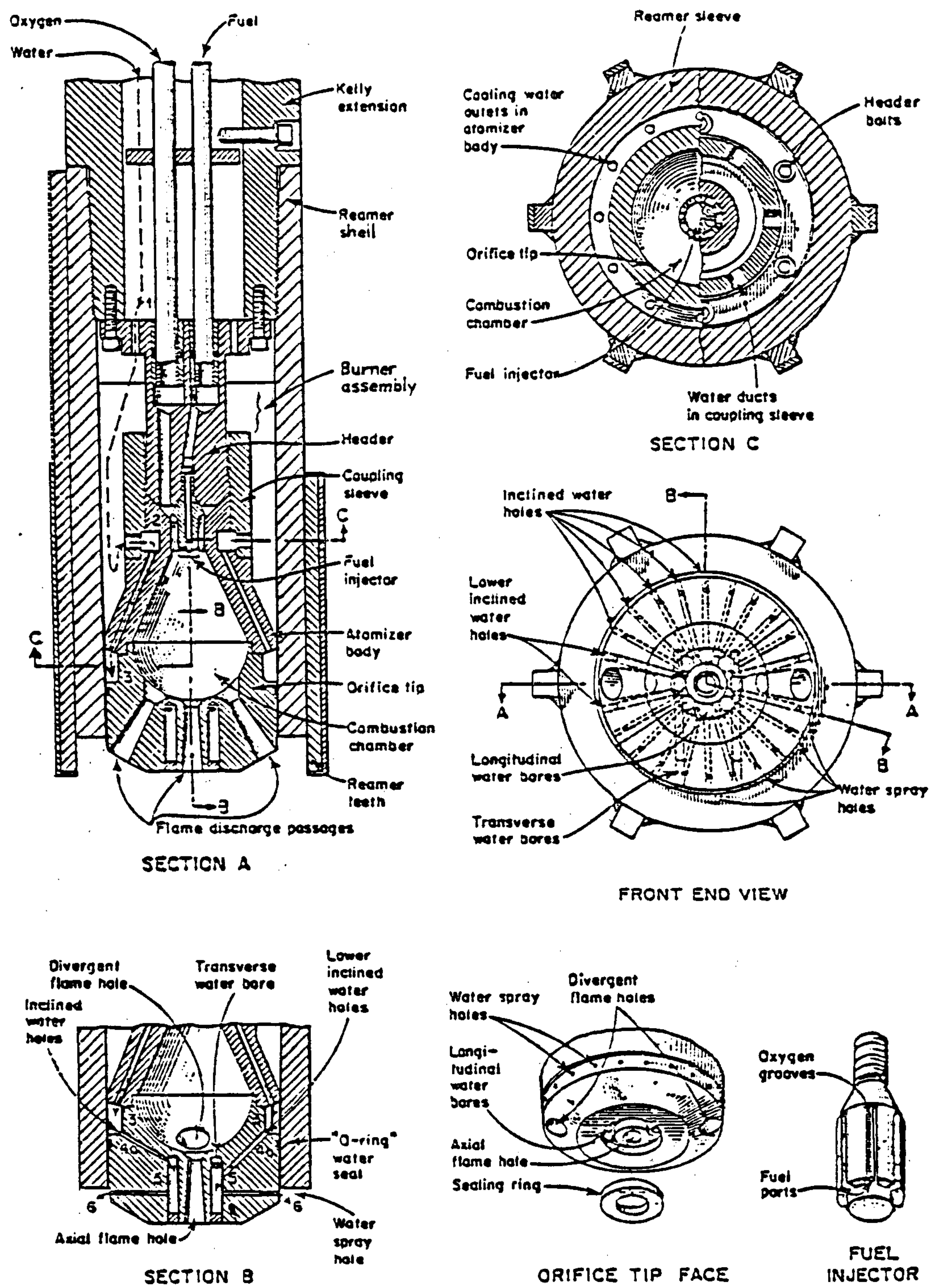
Figure 12

3. System Description

Linde's jet piercing system combines oxygen with No. 2 fuel oil in a water cooled, rocket type, combustion chamber, Figure 13. The exhaust gases and flame are expelled from the chamber through a nozzle and against the rock surface. These gases are approximately 4300°F. An optimum oxygen-fuel ratio by weight is considered to be 3.37. Using this ratio, optimum rock removal rates were noted when 13,500 CFH of oxygen was used, Figure 14. Linde uses a multi-nozzle burner that rotates at approximately 20 to 25 RPM when in operation. Extensive experimentation has led to average burner life of over 300 hours.

The concept of operation used in this system is to produce a flame that is aimed at the rock face to heat it and, in conjunction with the mass-velocity of the exhaust gases, produce a spalling action. When non-spallable rock or cracks are encountered, the exhaust gas temperature is high enough to fuse the rock. The molten rock is then blown away by a combined action of the mass-velocity of the exhaust gasses and the scrapping action of the burner reamer lugs. This type of operation is much slower than the spalling operation.

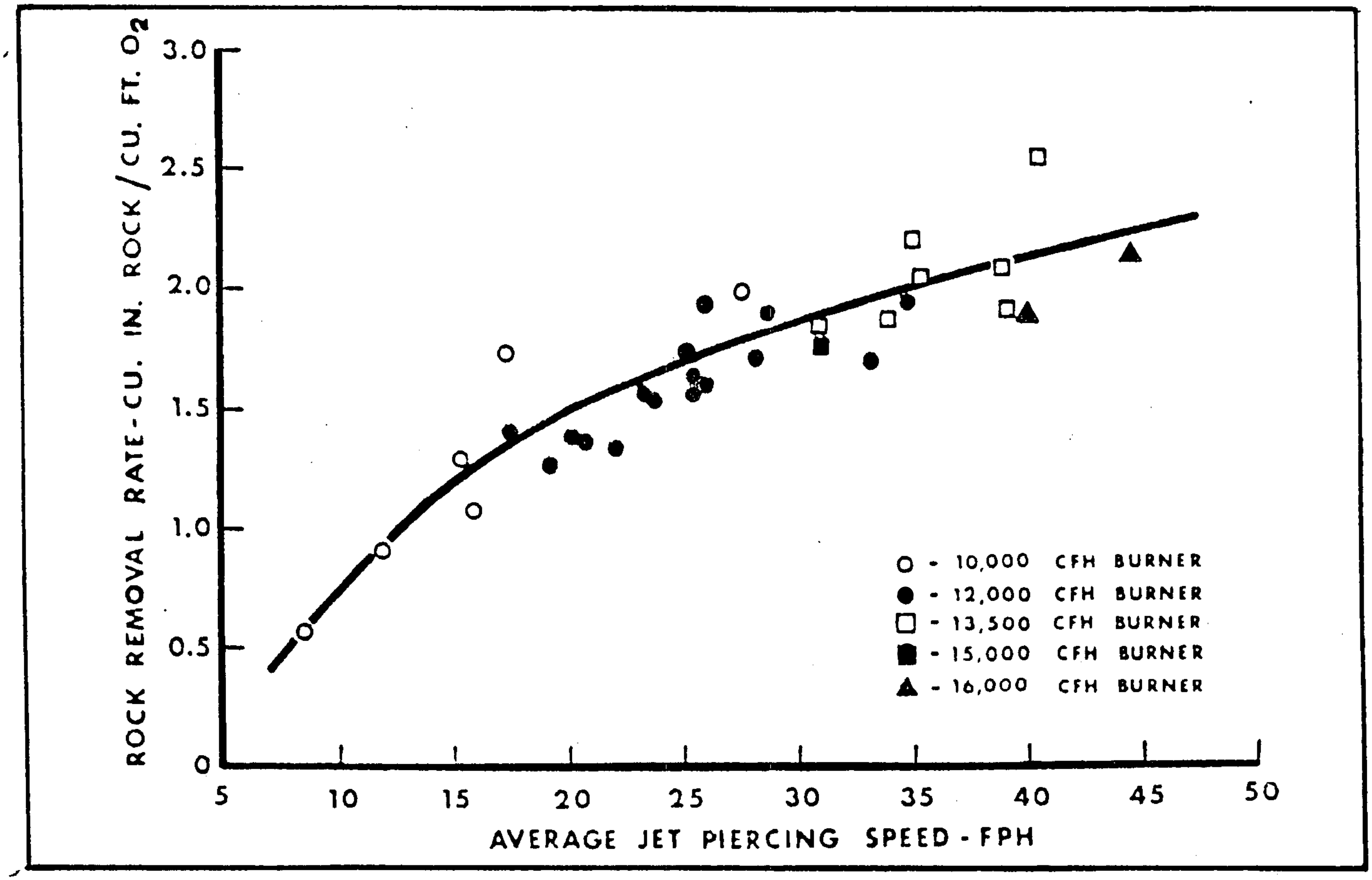
In operation, the burner is placed on the end of a long metal shaft. The burner is ignited on the surface by means of an external torch. The operating burner is then lowered into the hole and positioned four to six inches above the rock face. As the rock spalls, the burner is lowered further into the hole. As the spalls are produced, they are blown to the surface by the exhaust gases.



BURNER

LINDE JET PIERCING TOOL

Figure 13



LINDE JET PIERCING SYSTEM

OXYGEN UTILIZATION RATES

Figure 14

Auxiliary water is used to cool the combustion chamber, to quench the rock particles, and to assist in blowing the rock to the surface. The water nozzles, as noted in Figure 13, are located just aft of the burner face.

The latest model rig, the JPM-5, Figure 12, that is used to control this operation is semi-automatic in operation and can be controlled by one operator. An assistant operator is used when necessary to help with maintenance, auxiliary operations, etc. A brief description of the designs of previous Linde rigs that have led to the JPM-5 model is noted in Table 3.

4. Future Plans

At present, Linde has no plans to improve its rig or burner designs because of the highly unfavorable business conditions created by the closing down of most of the taconite mines. These mine closings have essentially shut down most of Linde's rig operations. If, however, the taconite industry improved, or other uses for jet piercing were to be found, Linde would increase its activity in this business.

5. System Evaluation

Linde has developed a semi-automated system that is capable of successfully spalling and/or melting rock to produce hole. The system can be further automated and improved if needed. The system has significant capability.

JET PEIRCING MACHINE SPECIFICATIONS

Table 3

	JPM-3	JPM-4	JPM-5
Operating Weight, tons	42.0	46.0	87.5
Overall Length, ft.	22.5	23.7	31.3
Mast Height, ft.	69.0	73.0	82.5
Design Hole Depth, ft.	50.0	56.0	64.0
Overall Width, ft.	12.5	15.4	17.6
Width Over Crawlers, ft.	11.9	14.9	15
Hydraulic Jacks	4	3	4
Diameter, in.	6	7	7
Stroke, in.	36	54	54
Main Transformer, KVA	75	150	225
Propulsion Drive	Electric	Electric	Hydraulic
Fuel Oil Capacity, gals.	525	523	850
Type Control	Manual	Manual	Microprocessor

C. Flame Jet Partners, Ltd., Encino, California

1. Background

In 1972, Messerschmitt-Boelkow-Blohm (MBB), Germany, received a contract from the Phillipine government to work on several projects that required the use of rocket engine technology. One of these projects was the drilling of water wells. Mr. Werner Baum, a rocket engine scientist for MBB was asked to head up the total program. After four years of this work, Werner Baum left MBB in 1976 to become Vice President of a newly formed company, Process Engineering International (PEI), Canoga Park, California. This company was dedicated to patenting and developing a flame jet drilling system that used a very high temperature rocket engine. Over the next few years a number of patents were obtained and a test rig was built. The rig was successfully tested on different types of hard rock, including hematite, granite, sandstone, etc.

In 1982 PEI assigned all of its patents, materials, and equipment to Flame Jet Partners, Ltd. (FJP), Encino, California, who in turn was to raise sufficient capital to commercialize the flame jet drilling system for deep drilling.

2. Operational Status

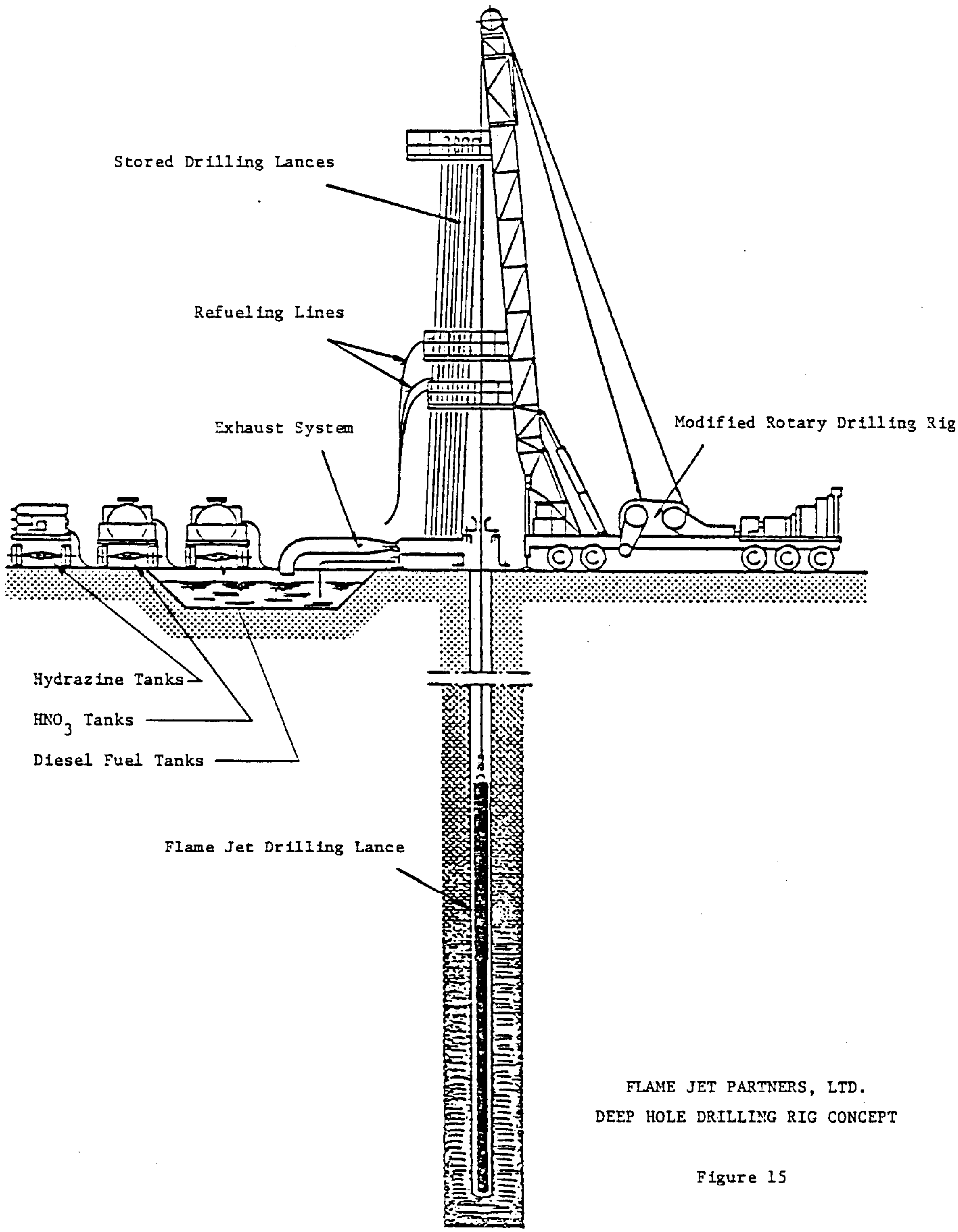
PEI designed, built, and tested only one jet drilling unit. This rig was built primarily to test the concept and thus it has very limited drilling depth capability (approximately ten feet). After drilling a number of test holes in different locations, and proving the capability of the system, the rig was stacked in a yard in Fort Worth, Texas. At present the rig is not being operated.

3. System Description

The test rig built by PEI consisted of a mechanism capable of lowering a kelly into the ground. An advanced design is noted in Figure 15. A combustion chamber, located on the end of the kelly, combines and mixes the fuel, hydrazine, and the oxidizer, nitrogen tetroxide, Figure 16. The hypergolic type reaction of these two liquids creates ignition of the combined fluid mass. The hot gases, approximately 7000°F, are then exhausted through the combustor nozzle in the form of a wedge shaped jet. In field operation, this exhaust gas is aimed at a rock face. Rotation of the kelly provides alternate periods of intense heat on the rock face. PEI claims that this hot-cold cycling assists in the spalling process. For non-spallable rock zones, the exhaust gas temperature is high enough to fuse the rock. When this happens, the combined effects of the mass-velocity of the gases and the scrapping action of the lugs on the combustion chamber shield can blow away the fused rock.

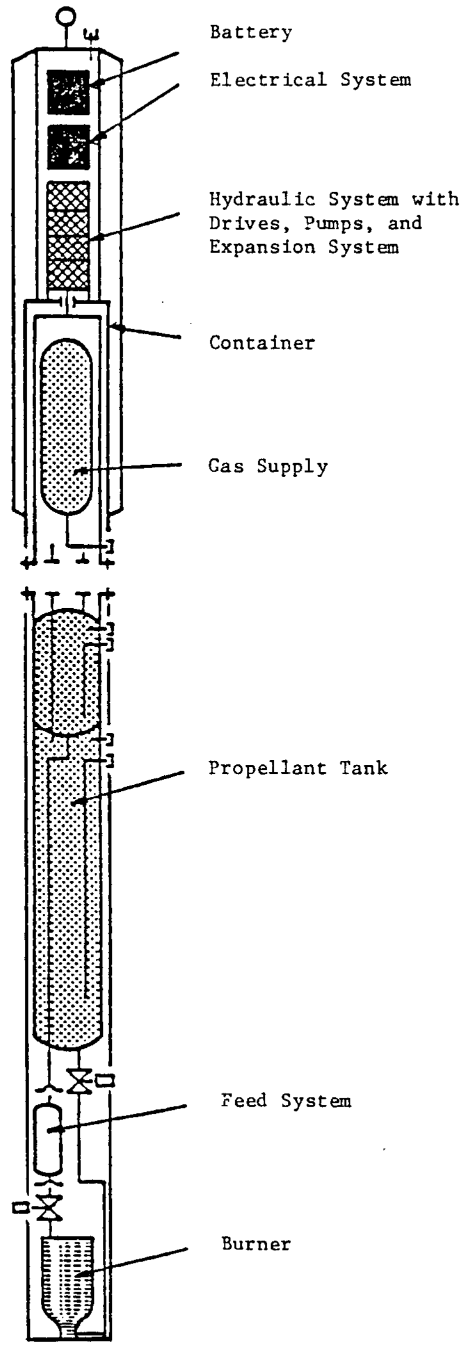
Ignition of the fuel-oxydizer mixture is due to hypergolic action. Because of this, it is claimed that ignition control, start and stop, can be obtained by a valving system that controls the flow and therefore the interaction of these liquids.

A water system is required to cool the combustion chamber and to enhance the spalling process. It is recommended that the water be deionized to avoid build-up of deposits in the system.



FLAME JET PARTNERS, LTD.
DEEP HOLE DRILLING RIG CONCEPT

Figure 15



SELF-CONTAINED ROCKET ENGINE
DRILLING LANCE

Figure 16

4. Future Plans

The future of FJP is dependent upon the ability of the company to raise funding for the development of the deep drilling rig and other applications. Until these funds are available, no additional work of any kind will be done with this system.

5. System Evaluation

This system is extremely complex when compared to the Linde system and the Browning system because of the type of fuel and oxidizer used and the handling problems involved. In addition, the concept of placing the fuel tanks down hole presents certain dangers and the requirement of far more tripping time to continually replenish the fuel supply. With additional design work, some of these problems could be eliminated. The system must be considered experimental in nature.

D. Comparative Analysis

On a comparative basis, the three systems previously described are as noted in Table 4. Although all three are concerned with the spalling process, there are significant differences in each system.

It should be noted that even though a number of drilling rigs were built, few if any are working at present. This is not due to the fault of the equipment or the concept. This is due to the shut down of many of the quarries that use this type of equipment. In reality, the number of rigs built and the number of feet drilled attest to the fact that thermal spallation is a viable and effective drilling technique when used properly. Further, as noted in Table 4, significant differences can be designed into a system and still produce acceptable results. Thus the concept has a degree of design flexibility.

COMPARATIVE ANALYSIS

OF

EQUIPMENT DESIGNS AND UNITS BUILT

TABLE 4

	Browning Engineering, Inc.	Linde Division, UCC	Flame Jet Partners, Ltd.
Max. Depth Drilled (Ft. approx.)	1086 (1)	200	10
Oxidizer	Air	Oxygen	Nitrogen Tetroxide
Fuel	No. 2 Fuel Oil	No. 2 Fuel Oil	Hydrazine
Exhaust Gas Temp. (°F approx.)	3300 °F	4300 °F	7000 °F
Type of Burner	Single Nozzle	Multi Nozzle	Wedge Shaped Nozzle
Nozzle Rotation	No	Yes	Yes
Drill Rigs Built	1	42	1
Drill Rigs Operating	0	Unknown	0
Channelers Built (Approx.)	400	200	0
Channelers Operating (Approx.)	250	50	0
Relative Drilling Costs at Comparative Drilling Rates	Low	Intermediate	High

Notes: (1) A modified system drilled a 1400 ft. hole in ice in the Antarctica

V. AREAS OF POTENTIAL USE FOR THERMAL SPALLATION DRILLING TECHNOLOGY

Flame jet drilling is a technology that possesses two unique attributes. The first is its potential ability to drill holes in certain types of hard rocks at very high penetration rates. The second attribute is its ability to create chambers or to enlarge areas at the bottom of very narrow holes, as illustrated in Figure 8. Both attributes are common only to this type of drilling.

With regard to the first attribute, the value of the system is limited to making hole in only those types of rock that will spall. In general, these rocks are very hard, crystalline type structures. Other, softer type rocks will also spall, but at a lower penetration rate. Considering these facts, the following hole drilling applications should be reviewed.

- Oil and Gas Wells
- Geothermal Wells
- Hot Dry Rock Wells
- In-Situ Leaching
- Mining Operations
- Water Wells

Of the above uses, oil and gas wells present the largest potential because of the number of wells drilled. Further, these wells normally penetrate sandstone, limestone, and/or dolomite formations. Both sandstone and dolomite have shown tendencies to spall. However, because a very high temperature flame jet is used for the drilling operation, a potentially dangerous situation could develop in which the high temperature flame ignites the oil or gas in the reservoir and causes a very serious explosion. For this reason it is extremely doubtful that any oil or gas operating company would allow their fields to be drilled with this method. This fact alone will eliminate this market area.

Geothermal well drilling presents an interesting application. Its value, however, is constrained by the type of rock formations that must be penetrated and the methods used to control the flow of reservoir fluids into the well. If the well is a dry steam well and the rock formations are suitable, flame jet drilling may find a possible application. However, if the rock formations are not suitable and/or the wells flow hot water, the use of this technique to drill the wells is very questionable.

The drilling of hot dry rock wells presents a very unique use because of the hard rock formations that must be penetrated and the generally dry drilling conditions. This application should be fully evaluated because of the potential it represents.

In-situ leaching refers to a mining process whereby wells are drilled into mineral bearing formations. Acids or other leaching agents are then injected into the formation and forced to flow to producing areas. The drilling of the wells could present interesting applications for flame jet drilling. Unfortunately, the market for this type of work is very limited and therefore the potential it offers is negligible.

Mining operations presents the largest use of this type of drilling to date. As noted in previous sections of this report, blast hole drilling and channeling have used this technology to a large degree. In recent years the use of this technique has declined due to the decreased operation of U.S. taconite quarries and the improvements in conventional rotary drilling bits. Channeling operations have fortunately kept pace with the growth of the rock cutting industry.

The drilling of water wells in hard rock country may offer a small market, but this will be essentially shallow well drilling. This type of drilling will not allow the development of more advanced systems.

The second attribute of flame jet drilling, chambering, may offer some opportunity because of the uniqueness of the operation. This concept has been used extensively in the enlargement of sections of blast holes. Other uses for it may be found in the development of underground chambers for

- Nuclear or Hazardous Waste Disposal
- Fuel or Gas Storage
- Military Applications

The development of underground chambers for the permanent storage of nuclear or hazardous waste materials could present a small, specialized market. Fractures or cracks in the rock formation, which might provide leakage from the chamber, could be overcome by solidifying and then pulverizing the waste material into nondissolvable, marble sized components. This material could then be poured into the underground chamber.

Fuel or gas storage in underground chambers may be difficult to do because of the problem of leakage through rock fractures and cracks. Thus the potential of this application is very limited.

The use of chambering may have some military application, but this must be discussed in detail with various agencies, such as DARPA and DARCOM, before any assessment can be made. The uniqueness of the chambering concept could lend itself to some military use.

Considering the above applications, several stand out as having realistic market potential. They are the drilling of dry steam geothermal wells, hot dry rock geothermal wells, and the chambering or building of caverns for hazardous waste storage. These markets should be more fully investigated to determine their true potential.

VI. THERMAL SPALLATION DRILLING RIG DESIGN

A. Design Overview

To effectively evaluate flame jet drilling, a conceptual design of a drilling system that can either rotary drill or flame jet drill as needed will be developed. This will be accomplished by integrating a thermal spallation drilling system into a conventional rotary drilling system. The design shall consist of three groups of equipment designed to reduce overall rig cost. The first group will contain those components used only for rotary drilling. The second group will contain those elements used only for flame jet drilling, and the third group will contain those components common to both types of drilling. During drilling operations, components required for rotary drilling will be used to drill through geological strata most conducive to that drilling method. Likewise, when drilling in granite or other similar rock, the flame jet drilling components will be used. In time, as experience is gained in thermal drilling and if use of this technology increases, it may be possible to design a single inexpensive rig capable of performing all functions. That design might include the use of a hydraulic heavy lift system for handling casing, a power swivel for drill string rotation, a drill pipe handling system, etc. This system should be less expensive than the combined rig concept defined above. The design of this rig, however, would be considered experimental and well beyond the scope of this study.

When evaluating the combined rig concept, it becomes apparent that the two rigs must be analyzed as a single drilling system consisting of a number of modules that can be integrated together when needed or set aside when not being used. Further, it becomes necessary to transfer the drilling function from one system to the other with little difficulty and little loss of time. Thus a systems approach that defines the function of each subsystem, their individual requirements for operation, their relationship to each other, etc., will be used. In this way all functions will be provided for, duplication will be eliminated, and proper and efficient relationships can be established.

B. Rig Specifications

The system to be designed must be capable of drilling the two wells illustrated in Figure 17. These wells are approximately 15,000 ft. and 14,000 ft. deep, respectively, with each deviating out as defined in Figure 18. Typical geological strata to be drilled and typical hole diameters and casing programs are also defined in Figure 17. It will be noted that approximately 2500 ft. of each hole is in geological strata that, in general, is not conducive to thermal spallation drilling techniques. In these zones, conventional rotary drilling methods will be used. Conversely, the remainder of each hole consists of granitic basement rock. In this formation, spallation drilling techniques appear to be superior to rotary drilling as far as penetration rates are concerned. Therefore, thermal spallation drilling techniques will be used in these zones.

The conventional drilling will be done by a rotary rig with a depth rating of 16,000 ft. to 18,000 ft. A rig of this size is needed to install the long casing strings required to rotary drill through the cement left inside the casing after a cementing operation (flame jet drilling cannot be used inside the casing because of the possibility of burning through the casing or damaging it), and to perform any surface drilling operation. The rig will be standard in design except for those portions that have been modified to convert to flame jet operations.

Thermal spallation operations will be done by a flame jet rig capable of using an air/fuel system, an oxygen/fuel system, or an air-oxygen/fuel system. The volume and characteristics of the fluids used in these systems are as follows.

GENER ELL MODELS

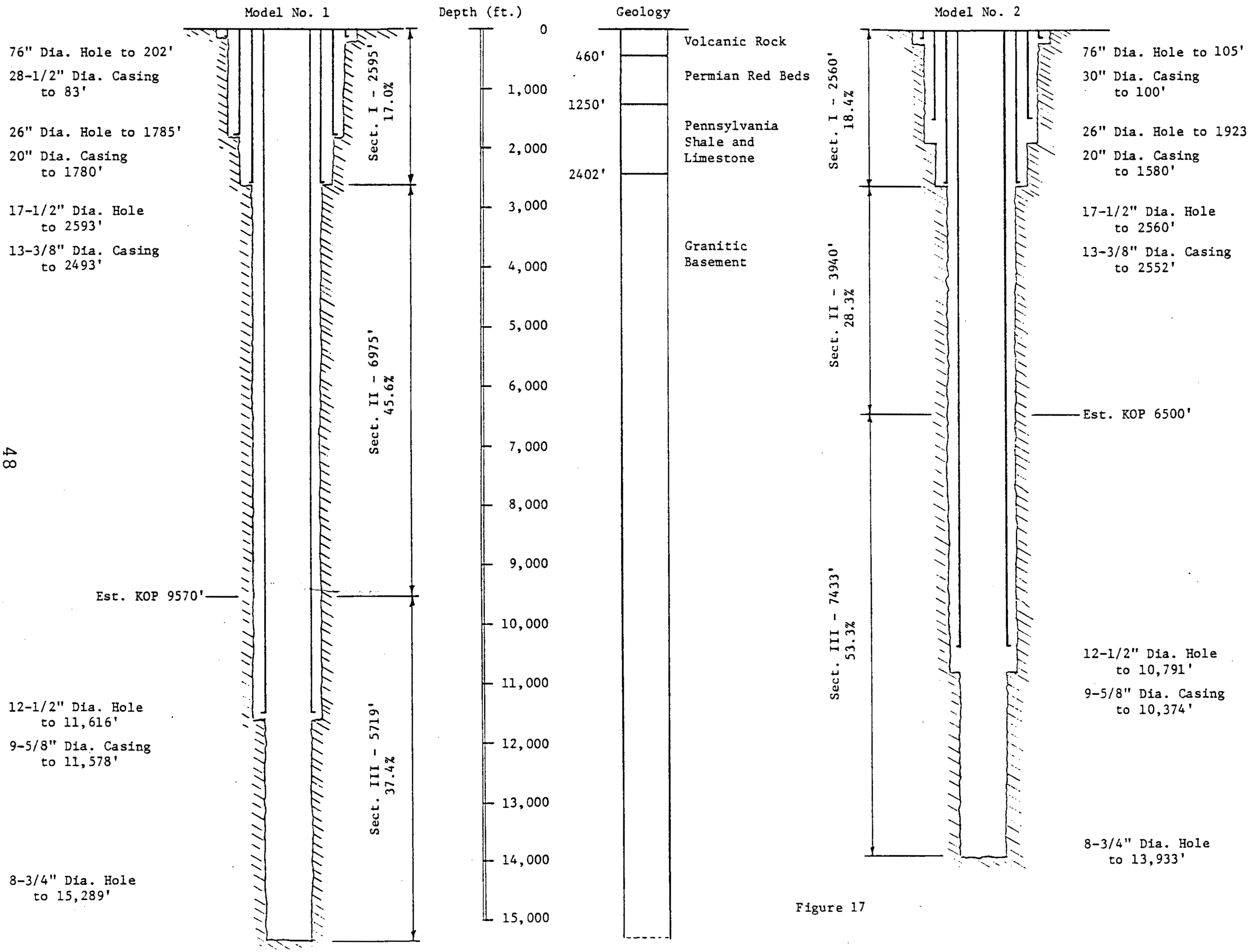
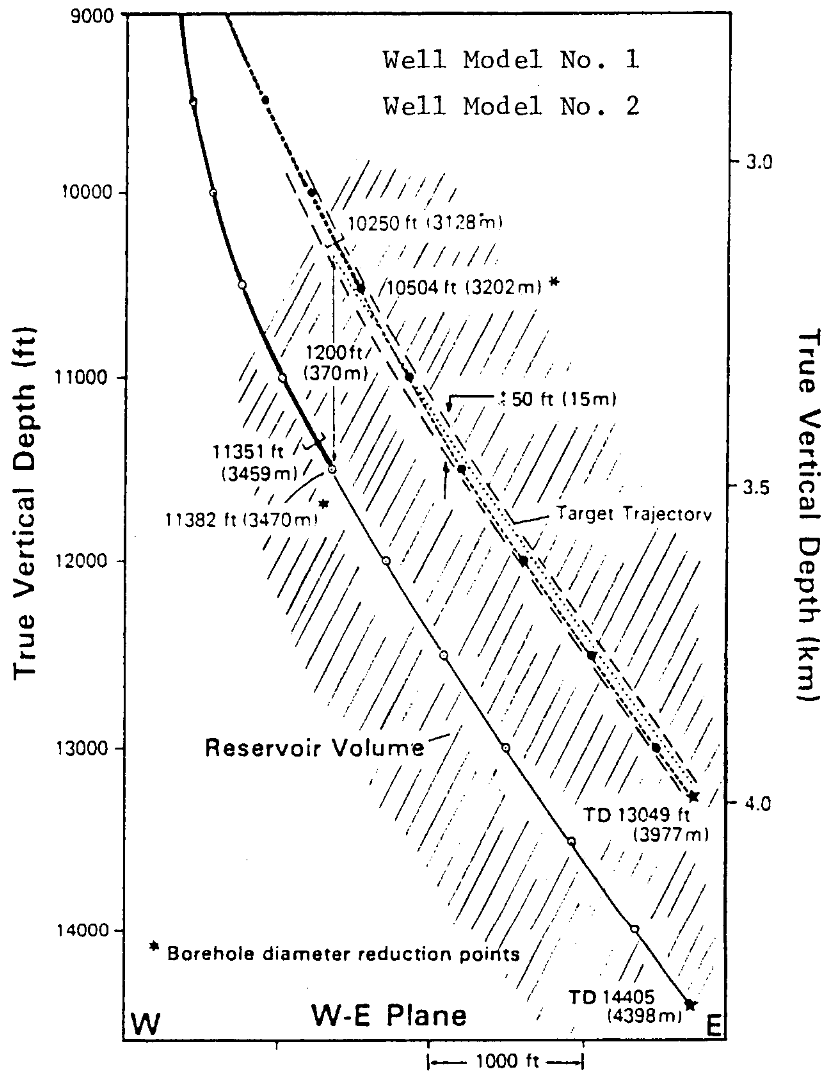


Figure 17



HOLE DEVIATION REQUIREMENTS

WELL MODEL NO. 1 AND WELL MODEL NO. 2

Figure 18

- Fuel

Because all fuels are essentially blends of different refinery runs, it is impossible to specify a fuel with specific characteristics. Thus fuel oils are classified according to characteristic ranges as noted in Table 5. In this design program, a No. 2 Fuel Oil will be used, as this type of fuel is used by both Browning Engineering and Linde Division of Union Carbide. Fuel calculations will be based on an average specific gravity of .855, which equates to a weight of 7.145 lbs. per gallon.

- Water

In flame jet operations, water is primarily used to cool the burner, cool the well walls, quench and thereby solidify molten particles of rock, and assist in the lift process. In this system design, water will be consumed at the rate of 20 gpm with a surface pump pressure of 200 psi.

- Air/Fuel System

When using a 100% air/fuel system, the volumes of air and fuel required will be as follows:

Air: 1200 SCFM @ 700 psi surface pressure

1 SCFM air = .0763 lbs. @ 60°F and 14.7 psia

Fuel: 40 gal/hr., No. 2 Fuel Oil

- Oxygen/Fuel System

When using a 100% oxygen/fuel system, the volumes of oxygen and fuel required will be as follows:

Oxygen: 225 CFM (13,500 CFH)

1 CFM oxygen = .0845 lbs. @ 60°F and 14.7 psia

Fuel: 47 gal/hr., No. 2 Fuel Oil

FUEL OIL CHARACTERISTICS

Table 5

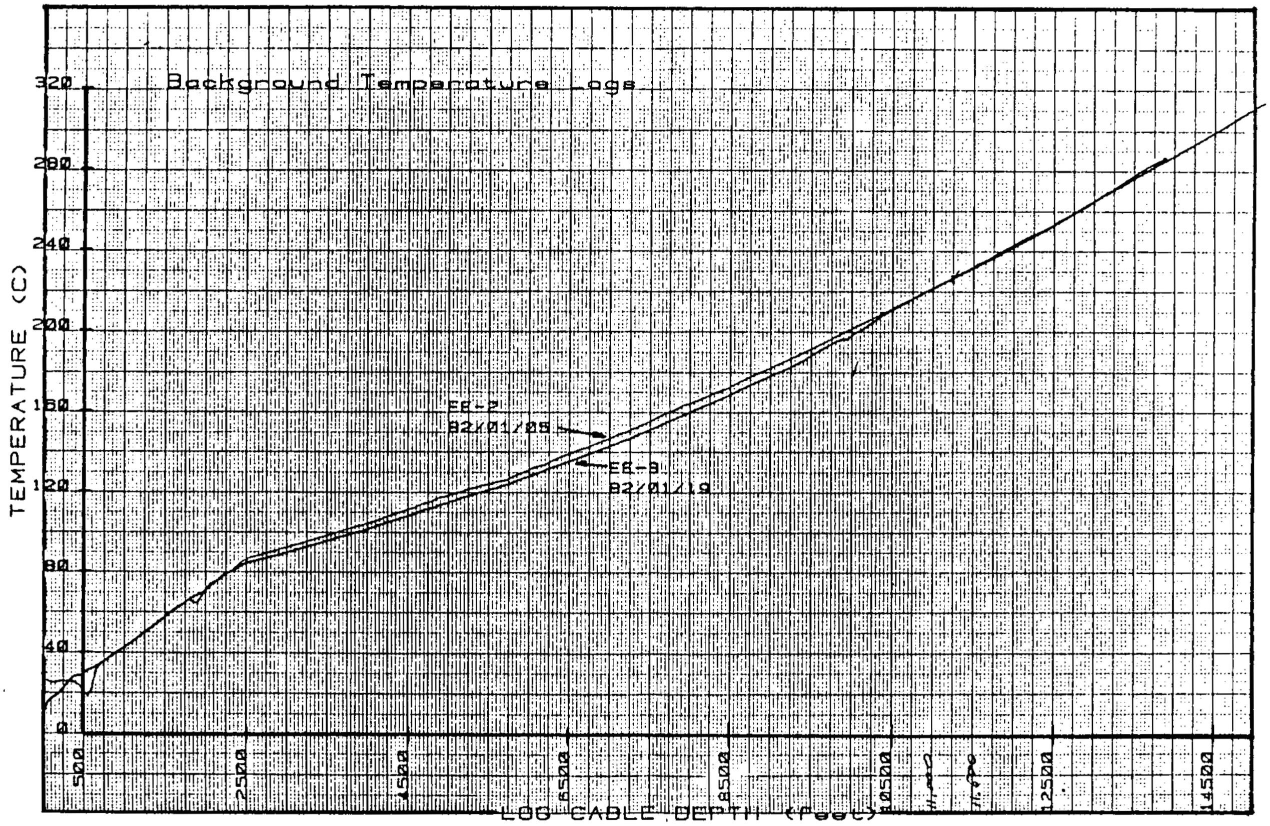
Characteristic	Kerosene	No. 2 Fuel Oil	No. 3 Fuel Oil
Cetane Number*	40 - 65	35 - 55	30 - 45
Distillation Temp. (°F)			
10%	370 - 400	400 - 440	480 - 510
90%	460 - 500	560 - 590	600 - 660
End Point	510 - 575	600 - 650	700 - 775
Heat of Combustion (BTU/gal.)	132,400 - 135,800	138,200 - 140,600	140,600 - 143,100
Specific Gravity	.797 - .825	.845 - .865	.865 - .887

* A measure of ignition quality; the higher the number, the easier to ignite.

Note - a 3.27 oxygen/fuel ratio is used in determining required fuel consumption.

Specifications for the various flame jet rig components will be discussed in detail in subsequent sections of this report. One specification, component design temperature, must, however, be given special attention because of the difficult problem it presents.

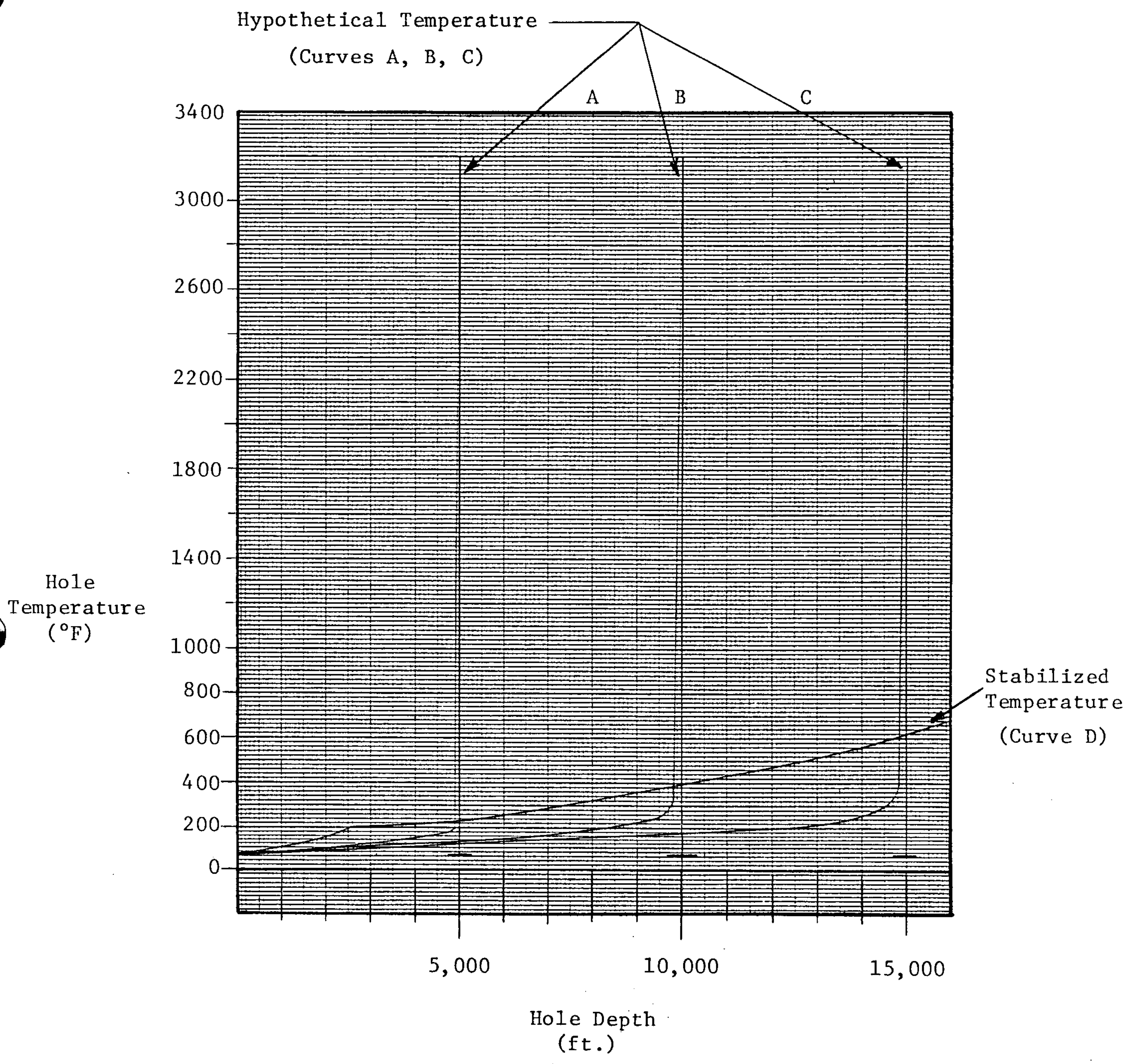
In some formations similar to those illustrated in Figure 17, bottom hole temperatures can be very high. Holes drilled in similar formations by Los Alamos Scientific Laboratories (LASL), Los Alamos, New Mexico, indicated stabilized bottom hole temperatures in the ranges noted in Figure 19. However, it has been argued that when using a thermal spallation drilling system, the temperatures experienced by the equipment in the hole during drilling operations are considerably lower, and may be in the order of the termperatures noted in Figure 20. In this graph, profiles of hypothetical hole temperatures (Curves A, B, and C) as might be seen during drilling operations are compared against the actual stabilized hole temperatures, Curve D, of Figure 19. Curves A, B, and C represent what the hypothetical profile might be when the flame jet burner is operating at depths of 5,000 ft., 10,000 ft, or 15,000 ft. The hypothetical curves indicate a very sharp temperature peak (spike) at the bottom of the hole. This peak is created by the very hot burner exhaust gases as they leave the burner. The gases then cool rapidly as they rise through the well bore because of the cooling effect of the water jets aft of the burner, the thermodynamic characteristics of expanding gases, and the low well wall temperatures. Well wall temperatures are considered to be low because of initial well wall cooling due to absorption of heat by the flowing well bore gases, and the low thermal recovery rate of well wall rock due to the low heat transmission rates of



LASL WELL TEMPERATURE PROFILES

EE-2 AND EE-3

Figure 19



TEMPERATURE PROFILES
DURING DRILLING OPERATIONS
FOR
5,000, 10,000 AND 15,000 FT. HOLES

Figure 20

rock from their inherent heat sources. Because wells of these depths have never been drilled by means of thermal spallation, no real data is available. A detailed thermodynamic model of the system that would better indicate what these temperatures are could be developed. However, that is beyond the scope of this report.

Determination of hole temperature is important because of the effect it has on materials used in drilling equipment. This is particularly important if the equipment becomes stuck in the hole and soaks at the stabilized hole temperature. If the equipment is not designed to survive at these temperatures, it could be severely damaged.

A summation of all of the above design specifications is as follows:

- One control system for both drilling methods.
- Depth rating of 16,000 ft. to 18,000 ft. This includes mud system, power system, hoisting capability, etc.
- Complete self-supporting system with its one prime power system, full mobility, etc.
- Complete capability to drill deviated holes.
- Complete capability to rotary drill to full depth.
- Complete capability to thermal spallation drill to full depth.
- Quench and efficient capability to change from one drilling system to the other.
- <u>All</u> down hole equipment will be designed to effectively operate and survive in temperatures similar to Curve D, Figure 20.

C. Rig Design

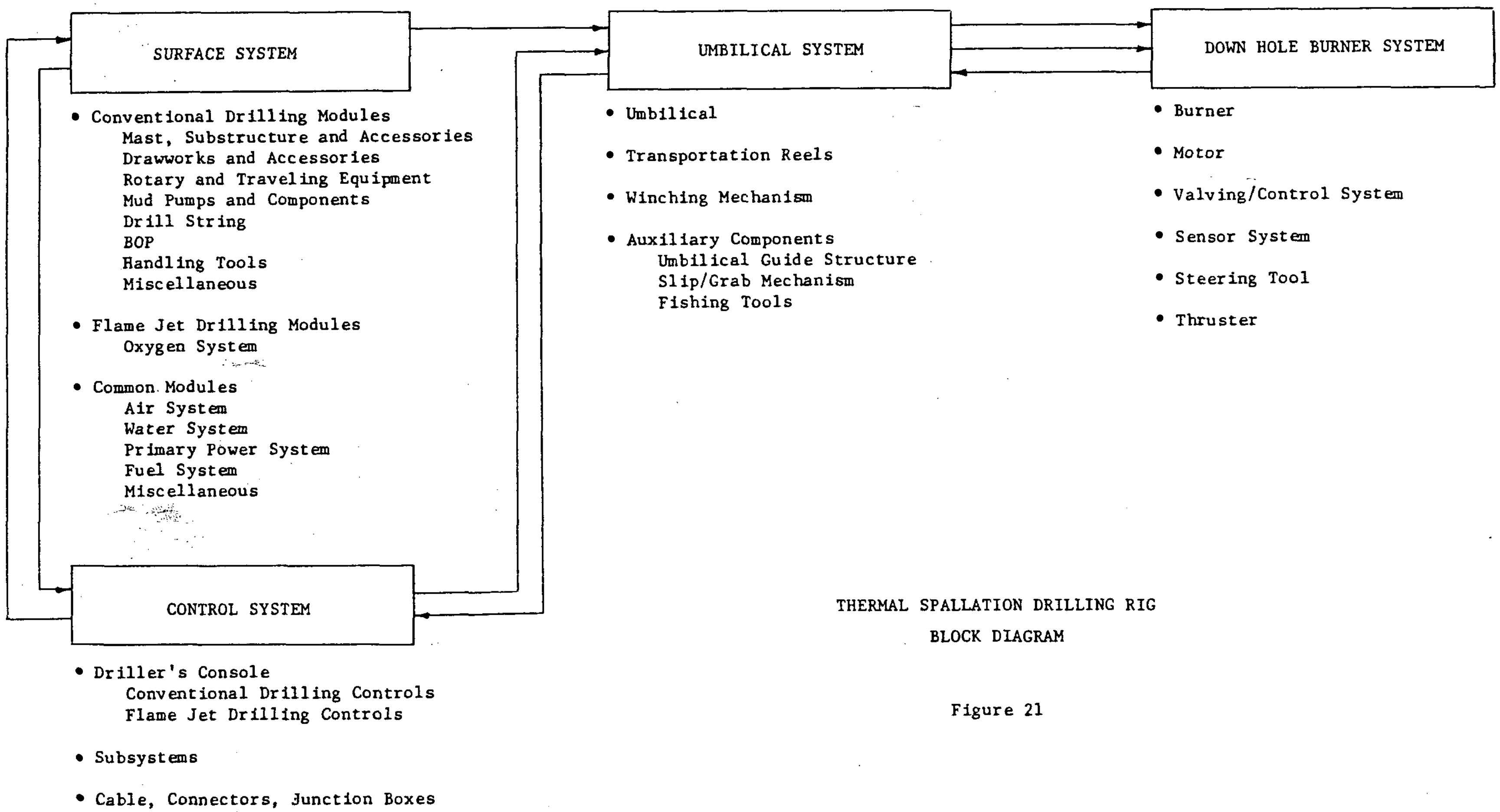
The envisioned rig design integrates a flame jet drilling system into a conventional rotary drilling rig as noted in Figure 21. The concept consists of four main systems and/or components as follows:

- Surface System
- Umbilical System
- Down Hole Burner System
- Control System

Each system or component incorporates a number of sub-systems, all of which are modular in design and integrated together so that one can either drill with conventional rotary equipment or flame jet equipment as desired. In the succeeding parts of this report, each system and auxiliary component will be reviewed and/or conceptually designed to that degree which will allow one to understand its capabilities and its design constraints.

All components will be economically evaluated to determine a fair cost. When possible, component cost will be based on actual costs obtained from vendors. A cost estimate shall be made where actual costs cannot be obtained.

Cost estimates shall assume that the components are made in quantity and that engineering costs are <u>not</u> included. In this way an estimated cost can be developed that will be on a fair and equitable basis with the cost of standard equipment obtained from vendors. The cost evaluation shall further assume that the component can be made in a reasonable manner and that its design will provide an efficient and reliable system. This last assumption is a major factor that must be fully understood as one progresses in this report.



THERMAL SPALLATION DRILLING RIG

BLOCK DIAGRAM

Figure 21

1. Surface System

As indicated in Figure 21, the surface system is divided into three separate groups of components. The first group consists of a series of modules that are used only for conventional drilling operations. The second group consists of modules used only for flame jet operations, and the third group consists of modules that are common to both drilling operations. It should be noted that there are additional surface components, but they are classified with the other equipment systems.

Conventional Drilling Modules

Most of the equipment required for conventional rotary drilling is included in this group. In general, they are standard oil field components and require no modification for use with this system. A list of these components is as follows:

- Mast, Substructure, and Accessories

  Mast, Substructure, BOP Hoist, Catwalks, Pipe Racks, Standpipe and Manifold, Wireline Guide Assembly, Hanging Assembly, Deadline Stabilizer

  Estimated Cost: $800,000

- Drawworks and Accessories

  Drawworks, Breaking System, Sand Reel Assembly, Crown Safety System, Catline Grip Assembly, Rotary Table Emergency Drive

  Estimated Cost: $415,000

- Rotary and Traveling Equipment

  Hook, Traveling Block, Swivel, Sandline, Wire Rope and Reel, Kelly, Kelly Bushing, Kelly Wiper, Kelly Valves, Rotary Table, Rotary Drive, Master Bushing, Rotary Hose

  Estimated Cost: $260,000

- Mud Pumps and Components

  Mud Pumps, Pulsation Dampeners, Vibrator Hose, Mud Tanks, Shale Shakers, Desanders, Desilters, Mixing Equipment, Suction Hose

  Estimated Cost: $840,000

- Drill String

  Drill Pipe (16,000 ft.), Collars, Subs, Pup Joints

  Estimated Cost: $770,000

- BOP

  Blowout Preventers, Choke and Kill Manifold, Controls, Manifold System, Hydraulic System

  Estimated Cost: $325,000

- Handling Tools

  Elevators, Spinning Wrench, Tongs, Slips, Lift Subs, Safety Clamps

  Estimated Cost: $92,000

- Miscellaneous

  Dog House, Mud Storage, Hoist Lines

  Estimated Cost: $50,000

Flame Jet Drilling Modules

The second group of modules relates directly to flame jet drilling operations. This group includes all the equipment for the oxygen system

- Oxygen System

  The main components of the oxygen system, as noted in Figure 22, are the liquid oxygen storage tank, a high pressure pump, and the high pressure vaporization system. This type of equipment is readily available and is normally installed and maintained by an oxygen supply company.

  When the rig is drilling with a 100% oxygen fuel mixture, the amount of oxygen required per hour is 13,500 CFH, or approximately 120 gal. of liquid oxygen. If the rig is operated an average of 15 hours per day,

$$120 \text{ gph} \times 15 \text{ hrs.} = 1800 \text{ gal./day}$$

  Using an 11,000 gal. liquid oxygen tank,

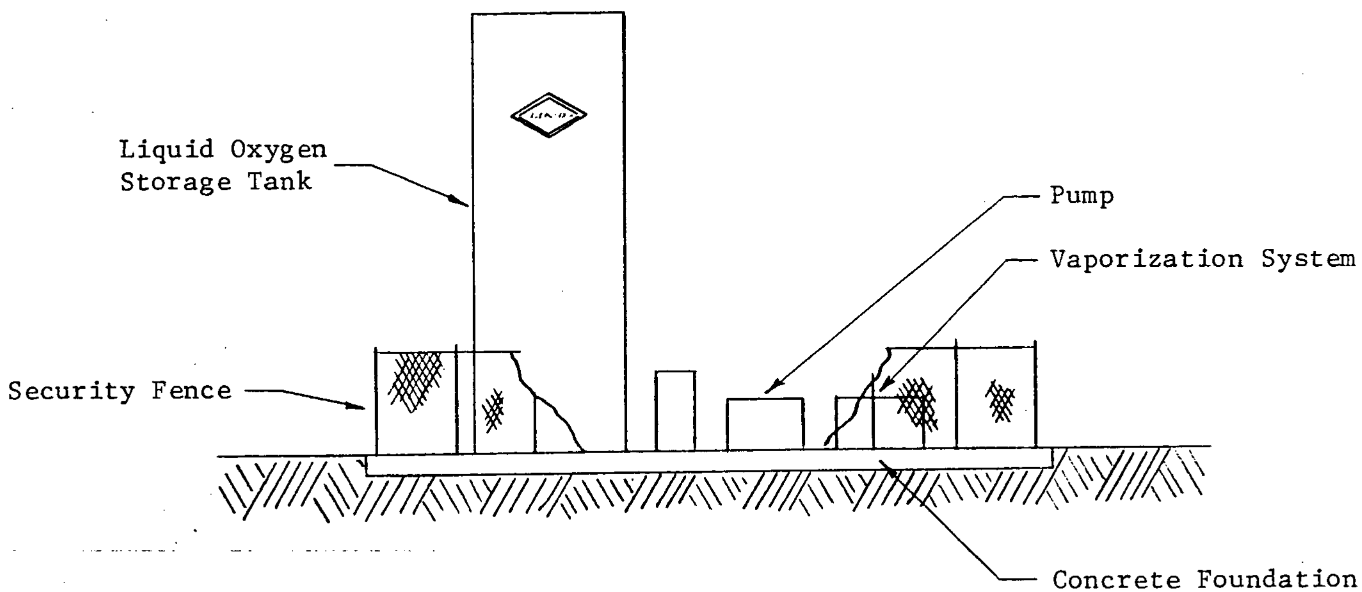
$$\frac{11,000}{1,800} = 6.1 \text{ days supply of oxygen}$$

  An 11,000 gal. liquid oxygen storage tank should be sufficient for this operation.

  Estimated Cost:

Concrete foundation	-	$ 2,000
Supplier operated tank and auxiliary equipment	-	$13,000
Supplier monthly operating charge	-	$ 2,500

  The cost of delivering oxygen to the supply tank is $.672/100 ft^3, assuming the oxygen generation plant is in Loveland Colorado, and the drilling site is in north



OXYGEN SYSTEM
(TYPICAL)

Figure 22

central New Mexico.

The oxygen system described above is a standard field type system. No problems are anticipated in obtaining and/or operating this type of facility.

Common Modules

Modules used for either flame jet drilling or conventional drilling include the air system, the water system, the fuel system, the power system, and miscellaneous components such as fire equipment and welding equipment.

- Air System

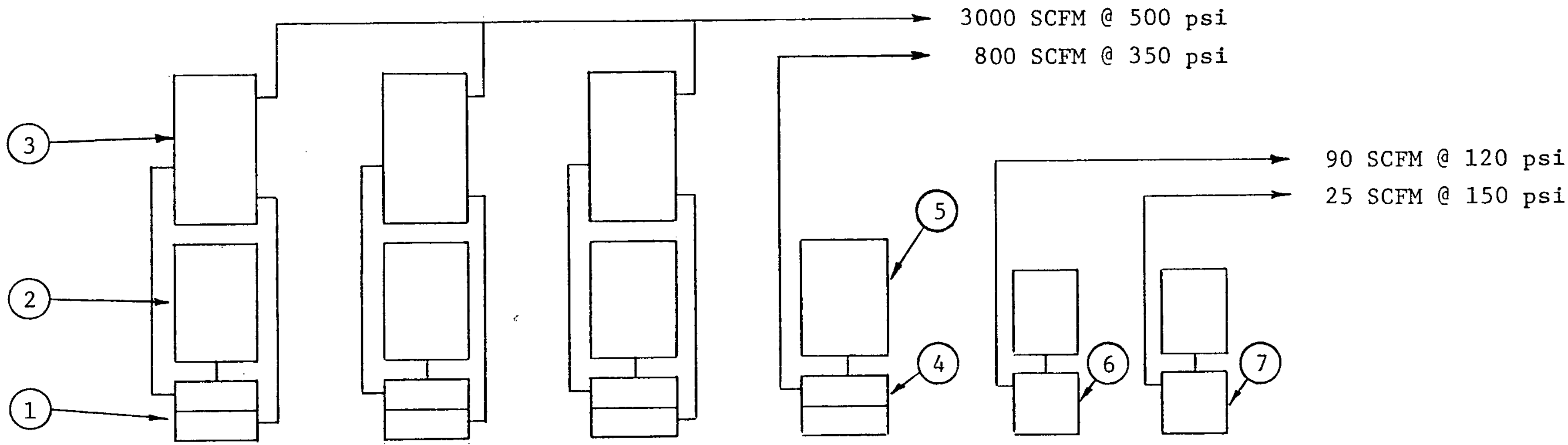
  The air system consists of the components noted in Figure 23. The components are divided into two subgroups: those used primarily for flame jet drilling and those used for rotary drilling. The flame jet drilling components are sized according to requirements that are defined in a later section of this report. The rotary drilling components are similar to those found on rotary drilling rigs of this size. It should be noted that all the compressors, with the exception of the Quincy DF325-60, are powered by electric motors. The Quincy DF325-60 is powered by a gas engine so that it can be used in rig up operations and/or other activities prior to the setting up of the prime power system.

  All components in the air system are standard and can be purchased with little difficulty. If additional compressed air is required, similar units can be obtained and easily added to the system.

- Water System

  Water is used primarily for the mud system and the flame jet cooling system. Water for the mud system is trucked in and normally stored in the mud tanks. Additional water may be stored in earthen pits or tanks as noted in Figure 24. Because of the requirements of the flame jet operation, tanks will be used. These tanks are standard oil field units and no difficulty should be

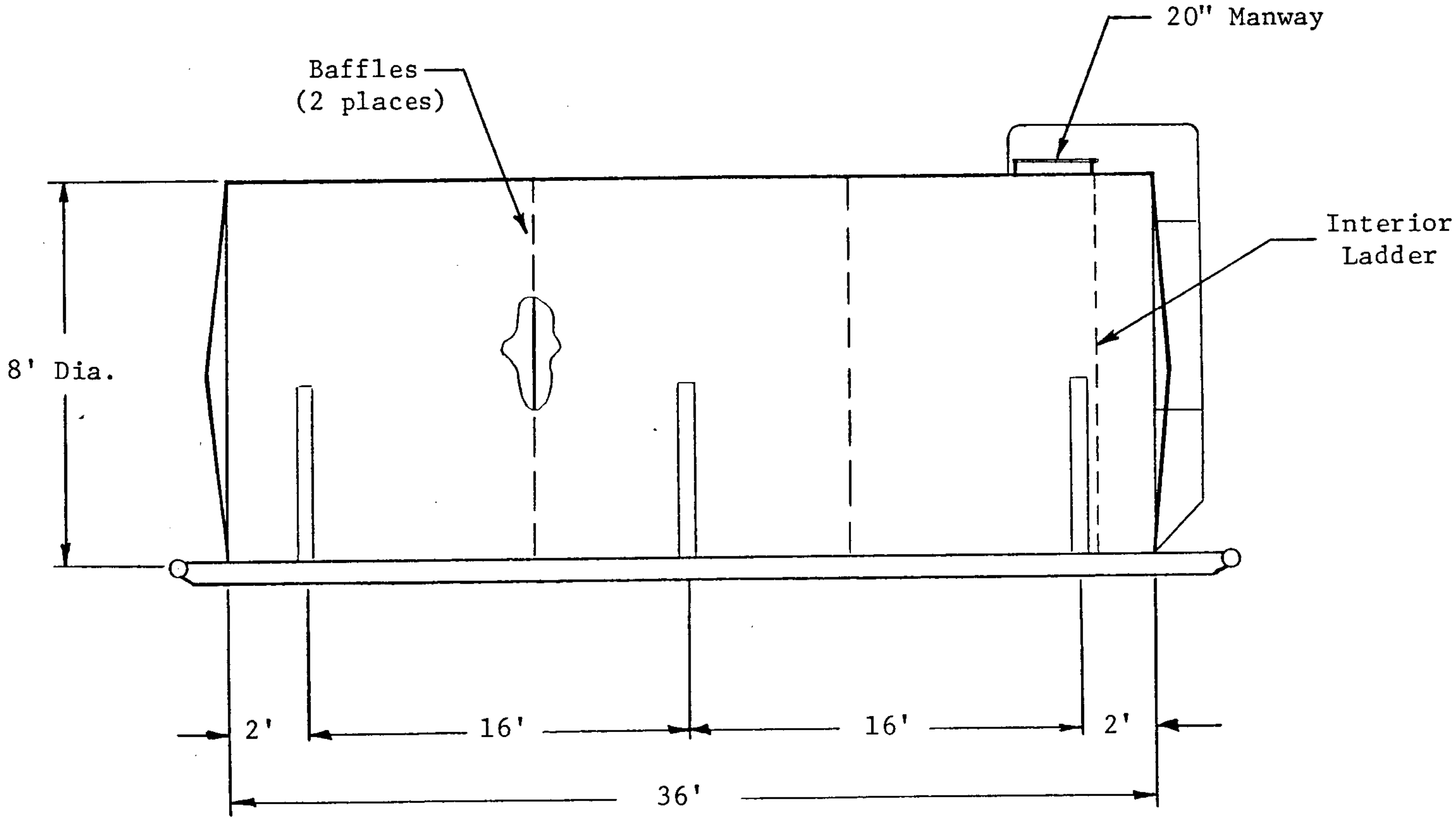
AIR SYSTEM



Item	Description	Quantity	Unit Cost $	Total Cost $
	• Flame Jet Drilling Air:			
1	Compressor, Ariel Corp., Model J/G-4	3	165,000*	495,000
2	Motor, G. E., 320 KW, 1200 RPM	3	32,000	96,000
3	Cooler, Air-X-Changer, Type H	3	-	-
4	Compressor	1	135,000	135,000
5	Motor	1	13,000	13,000
	• Rotary Drilling Air:			
6	Compressor & Motor, Quincy, DF390-120	1	3,900	3,900
7	Compressor & Motor, Quincy, DF325-60	1	2,950	2,950

* Includes Cost of Cooler, Item 3

Figure 23



WATER TANK

300 BARREL CAPACITY

Figure 24

encountered when obtaining this type of unit.

Based on the flame jet rig specification of 20 gpm utilization rate, 1200 gph or 28.57 bbl/hr. will be required. If the rig is operated an average of 15 hours per day, approximately 428 bbls of water per day will be required. Thus two 300 bbl water tanks will be required.

Estimated Cost:	Two Water Tanks	- $32,000
	Water Pumps	- $ 5,000

- Primary Power System

One primary power system will be used to power both conventional rotary and flame jet drilling equipment. This will be done by attaching the prime mover/generator sets to an SCR distribution system. This concept is the most efficient method of transferring and assigning total available horsepower from the prime movers to the various component motors. Each prime mover drives an AC alternator. The output of all alternators is combined on a common AC bus, which feeds the SCR bridges and switchgear. This makes the total output of all prime movers on line available to any SCR bridge. Each SCR bridge supplies the assigned DC motors, allowing control of each motor from 0% to 100% output.

The equipment used in this concept is all standard oil field equipment that requires no modification. It does, however, require an expanded control system because of the additional motors of the flame jet system.

The basic components of the system are:

4 - Caterpillar D398 Diesel Generator Sets, 60 HZ, 1200 RPM with fan, 565 KW continuous service

1 - SCR System including bridges, transformers, circuit breakers, controls, etc.

Cable trays, walkways, enclosures, etc.

Estimated Cost: $1,200,000

- Fuel System

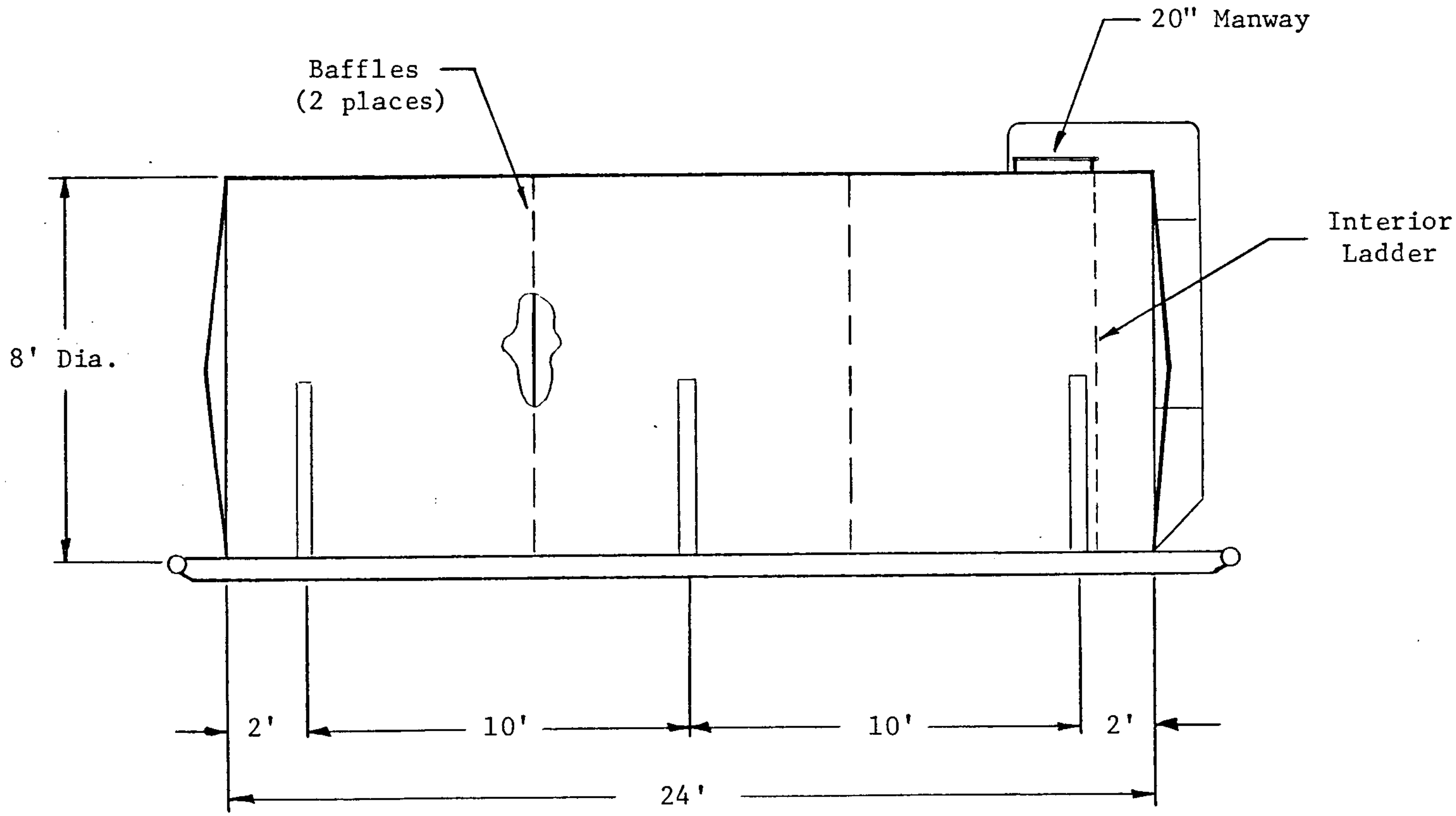
One central fuel system will be used to supply fuel to both the prime movers and the flame jet burners. As previously specified, No. 2 fuel oil will be used. Maximum fuel consumption rates are estimated to be 135 gal/hr. during tripping operations and 40 to 47 gal/hr. during flame jet drilling operations. When tripping, an average of 14 to 16 hours will be required for making a round trip from the deepest hole. This will require a minimum of 1500 gallons of fuel. When flame jet drilling, a minimum of 700 gallons of fuel will be required if the rig operates 15 hours per day. Considering these factors, one 9000 gallon fuel tank similar to that in Figure 25 will be required.

Estimated Cost:	One Fuel Tank	-	$11,000
	Fuel Pumps	-	$ 2,000

- Miscellaneous Components

The miscellaneous components consist of a series of tools and components used with either drilling system. They are standard oil field components and will need little or no modification.

Estimated Cost:	Fire Fighting Equipment	-	$ 20,000
	Hand Tools	-	8,000
	Tool House	-	20,000
	Wire Line System	-	12,000
	Welding Tools	-	5,000
	Rig Lights	-	20,000
	Other	-	30,000
	Total		$115,000



FUEL TANK

9000 GALLON CAPACITY

Figure 25

2. Umbilical System

The purpose of the umbilical system is to transfer the working fluids for flame jet drilling from the surface system to the down hole burner system, and to provide a physical and electrical control link between these two elements. It is used only for flame jet drilling operations. The main components of this system are:

- Umbilical
- Transportation Reels
- Winching Mechanism
- Auxiliary Components
    - Umbilical Guide Structure
    - Slip/Grab Mechanism
    - Fishing Tools

Most of these components do not exist in the form needed for this type of operation. Thus a design and test program will be required.

Umbilical

The umbilical is the main component of the umbilical system. Its function is to provide a means for transporting air, oxygen, fuel, and water from the surface to the down hole burner system. In addition, it must provide a physical means for transmitting electrical control signals and act as a mechanical link between the two systems.

The design of this component is extremely complex because of the number of physical constraints placed upon it. Abrasion resistance is the first of these constraints. Because of the abrasive nature of the well bore, and the flow of rock particles up the well bore, the exterior surface of the umbilical will be constantly exposed to an abrasive action. This action becomes particularly pronounced when the umbilical is tripped into or out of a deep, deviated well. During this operation the umbilical is moved rapidly across the inside radius of the well deviation curve. The rubbing of the umbilical against the wall surface will cause excessive abrasive action. Thus, one requirement of the umbilical is that its outer surface be abrasive resistant, or that it is held off the well wall by some type of sacrificial element.

Another design constraint is the high environment temperature. Regardless of which environment temperature curve (Figure 20) is used, the umbilical will see temperatures of 200°F or higher. Although many hoses are designed for operating at 200°F to 250°F, their operating characteristics drop off rapidly above these temperatures.

Flexibility is another design requirement. Regardless of the system chosen (hose, pipe, etc.), the system must be capable of being transported to and from the well site, and it must be capable of being handled at the well site.

System strength characteristics must also be considered. In all probability, the chosen system will be hung from the surface into the hole. This concept requires high tensile load carrying capability in the umbilical, particularly when deep hole operations are involved. This problem is compounded by the fact that most hoses are not designed to be hung by one end. Under these conditions the hose wrappings tend to separate. This is particularly true where the end connector grabs onto the hose. In addition, burst strength of the umbilical must also be considered because of some of the fluid pressures involved. These loads can momentarily be very high if the fluids, when flowing, are stopped rapidly due to the closing of a control valve, or the like, in the down hole burner system. Considering the high tensile load and potentially high burst pressure load, it will be necessary to take into account the combined stress load when designing the system.

The effects of oxygen, particularly at high temperatures, must be considered when chosing materials. Most materials react negatively to this element. This is particularly true of many synthetic materials. Although only one line will be exposed to an air/oxygen mixture, the outer surface of the umbilical will, at high temperature, be exposed to combustion gases, steam, and a small amount of unburned oxygen. In either case, the oxygen effect on the umbilical will be destructive.

In addition to these design problems, a very significant manufacturing problem exists. Most hoses of the type required for this system are manufactured in short lengths of 250' to 500' or less. Thus special, and probably very expensive, manufacturing processes must be developed. Conversation with manufacturers of hoses indicates that this may be a critical problem.

Other problems of concern include the design of hose connectors that can effectively grab onto a hose that is hung in tension, the destructive effect on the umbilical of the slip mechanism when it is closed in an emergency, the external configuration design of the umbilical so that a bladder type BOP can be closed on it in an emergency, etc. These problems and the others stated above are some of the main problems to be considered in this design. Others will occur as the design progresses.

When determining the actual conceptual design of the system, several concepts were considered, as noted in Figure 26. The first concept consists of a series of concentric hoses. The annular area between the different hoses would be used to carry the different fluids required. Water would be carried in the outer annulus to assist in cooling the inner hoses. The main load carrying member was considered to be a steel cable located in the center of the umbilical. This idea was, however, discarded because of the large diameter of cable required (3" or more in the upper umbilical sections) and the fact that when the umbilical was wrapped on a reel and under high end load, the steel cable, being in the center of the hose and not on a solid surface, would tend to crush the hoses beneath it. To eliminate this problem, the load carrying member was transferred to the outer surface of the umbilical. A heavy steel wrapped hose similar to those made by Coflexip in France would be used for this member.

To protect the umbilical from abrasion damage, the outer surface would be covered with a sacrifical sheathing along with oil field type rubber guards. The sheathing and rubber guards would be replaced as required.

Section lengths of this design would be based upon manufacturing problems, bend radius of the umbilical as it

UMBILICAL

DESIGN CHARACTERISTICS

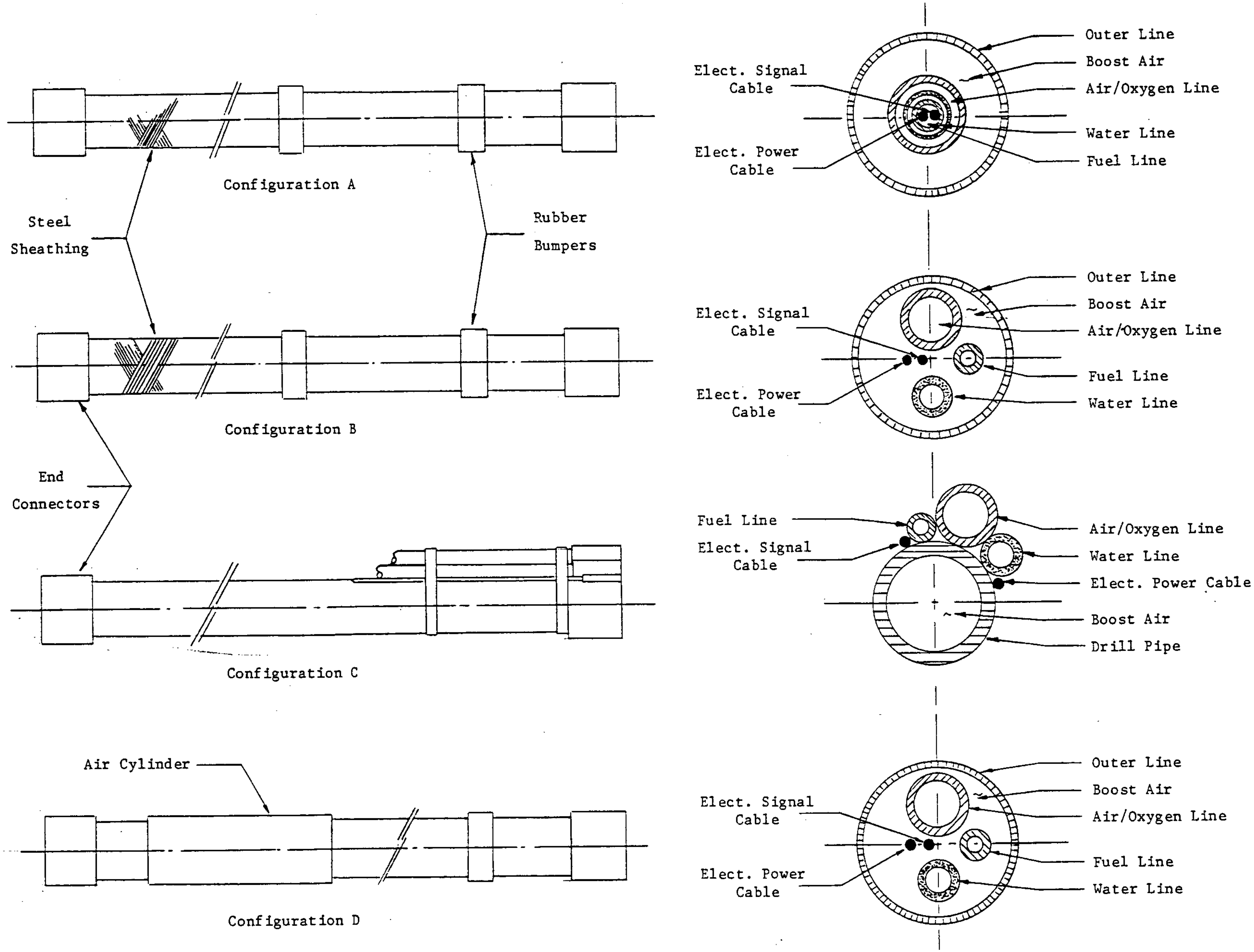


Figure 26

affects the design of the transportation reels, and the acceptable load carrying capacity of the transportation reels. Each section would be terminated with a male or a female connector. In this particular concept, designing the mechanism that attaches the connector to the individual concentric hoses may be very difficult because of the required tensile loads that must be considered and the configuration of the umbilical.

The second umbilical configuration is somewhat similar to the first except that the inner hoses are bundled together as opposed to a concentric configuration. All of the problems of the first umbilical design are also present in this configuration. Its advantage lies in the fact that it may be somewhat less expensive than the first because the inner hoses may be closer in size to standard hoses. In addition, the hoses may require less material, which would reduce tensile loads on the system and reduce the overall cost. It may also be easier to manufacture.

The third configuration is a LASL concept and consists of using the drill string as the load carrying member and strapping the extra fluid carrying lines to its side as it is tripped into the hole. This would eliminate the tensile load problem of the external hoses. However, this design could amplify the abrasion problem by constantly rubbing the external hoses against the well wall. Advantages of this design would be the simplification of the hose connector problem because each hose would have its own individual connector. Further, the hoses would all approach standard hoses in design, which would reduce manufacturing costs and overall hose cost.

A major advantage of this design is that the hoisting equipment for this system is already available in the form of the rotary drilling rig. If the umbilical systems of the first two designs is used, very expensive hoisting equipment must be developed.

A derivation of this design, as conceived by Linde Division of Union Carbide, utilizes casing cut in half and placed around the hose bundle. This would protect the hoses from abrasion and eliminate the load problem, as the hose bundle would be mechanically attached to the casing. The casing sides and end connectors would not have to be leak-proof as the only purpose of the casing is to carry the hose load and protect the hose bundle from abrasion. The split casing sections would be placed around the hose bundle as it is lowered into the hole.

The fourth configuration is a derivation of either the first or the second design. This design incorporates flotation modules in the umbilical to reduce or eliminate the tensile load problem. This concept will work only if the hole is flooded with water, and a plasma arc type rock heating device is developed to produce the spalling action. A major drawback to this design is the problem of lost ciruculation in highly fractured geological zones. Lost circulation obviously negates the flotation concept. In flame jet applications such as waste disposal caverns or where fractured zones are plugged, this concept may have some merit.

Considering the merits and problems of all of the above systems, the second concept shall be used in this report. The selection is based on the fact that it is simpler and probably less expensive than the first design, and it is far more protective of the hoses involved than the third design. It should be noted, however, that the Linde derivation of the third design is quite interesting and warrants further analysis.

Having selected an umbilical design and knowing the ratios of air and/or oxygen to fuel, it becomes necessary to determine the volume of boost air required to supplement the volume of combustion gases and steam so that rock chips can be effectively lifted to the surface. This is accomplished by first determining the volume of combustion gases and steam produced, and then subtracting these values from accepted standards of air volume required to lift the chips to the surface. After these values have been determined, it will be possible to conceptually design the umbilical.

As previously stated, No. 2 fuel is a blend of various production runs. Thus no specific formula is available to chemically define it. Considering this fact, C_8H_{18} will be used for analytical purposes in this study.

Volume of Combustion Gases - 100% Air/Fuel Process

- Combustion Equation:

$$C_8H_{18} + 12.5O_2 + 47.2N_2 = 9H_2O + 8CO_2 + 47.2N_2$$

Rel. Wts.:	114	+	400	+	1322	=	162	+	352	+	1322
Wt/lb Fuel:	1	+	3.51	+	11.6	=	1.42	+	3.09	+	11.6

- Weight of Fuel:

$$\text{s. g. of } C_8H_{18} = .703$$

$$1 \text{ gal } C_8H_{18} = (.7)(8.357) = 5.85 \text{ lbs}$$

- Fuel Required:

From specifications - 40 gal/hr

$$\text{Fuel req. lbs/min} = \frac{(40)(5.85)}{60} = 3.90 \text{ lbs/min}$$

• Air Required:

Air req. lbs/min = (3.90)(3.51 + 11.6) = 58.9 lbs/min

1 lb air @ 60°F and atmo. press. = 13.10 ft^3

Air req. ft^3/min = (58.9)(13.10) = 773 ft^3/min

• For Combustion Process Use:

Fuel - .667 gal/min

Air - 773 ft^3/min

• Volume of Combustion Gases:

Assume combustion properties - 3300°F (3760°R)

- 240 psi (254.7 psia)

Assume Univ. Gas Const., R_0 - 1545

$$V = \frac{wR_0T}{p}$$

$$V = \left(\frac{1.42}{18} + \frac{3.09}{44} + \frac{11.6}{28}\right)\left(\frac{(1545)(3760)}{(254.7)(144)}\right)$$

$$V = 89.2 \text{ ft}^3/\text{lb of fuel}$$

From above, 3.90 lbs fuel used per min

Therefore, (89.2)(3.90) = 347.9 ft^3/min

As the volume of combustion gases rises through the well bore, it will cool, be under less hole pressure, and enter into larger well bore areas. Thus it will undergo a volume change. This will be computed as follows:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Because, as previously noted, the question of true bore hole temperature has been raised, this computation shall be made considering both sets of temperatures.

Assume - P_1 = 240 psi (254.7 psia)

- T_1 = 3300°F (3760°R)
- V_1 = 347.9 ft^3
- Well bore diameter increase not considered
- Temperature T_2 will be obtained from Curves C and D, Figure 20

Volume Change - See Table 6

COMBUSTION PRODUCTS

100% AIR/FUEL

VOLUME CHANGE

Table 6

Hole Depth	Curve C				Curve D			
	Temperature T_2		Pressure P_2 (1)	Volume V_2	Temperature T_2		Pressure P_2 (1)	Volume V_2
ft	°F	°R	psia	ft^3	°F	°R	psia	ft^3
2,000	80	540	40	319	158	618	40	364
4,000	100	560	50	264	216	676	50	319
6,000	130	590	65	214	266	726	65	264
8,000	155	615	80	181	324	784	80	231
10,000	180	640	100	151	392	852	100	201
12,000	200	660	120	130	468	928	120	183
14,000	260	720	145	117	554	1014	145	165

(1) Ref.: - Angel, R.R., "Volume Requirements for Air and Gas Drilling", SPE-TP-4679, Oct., 1957.

- All pressure values doubled to compensate for heavier chip weight.

Volume of Combustion Gases - 100% Oxygen/Fuel Process

- Combustion Equation:

$$C_8H_{18} + 12.5O_2 = 9H_2O + 8CO_2$$

Rel. Wts.:	114	+	400	=	162	+	352
Wt/lb Fuel:	1	+	3.51	=	1.42	+	3.09

- Weight of Fuel:

s. g. of C_8H_{18} = .703

1 gal C_8H_{18} = (.7)(8.357) = 5.85 lbs

- Fuel Required:

From specifications - 47 gal/hr

$$\text{Fuel req. lbs/min} = \frac{(47)(5.85)}{60} = 4.58 \text{ lbs/min}$$

- Oxygen Required:

Oxygen req. lbs/min = (4.58)(3.51) = 16.08 lbs/min

1 lb oxygen @ 60°F and atmo. press. = 11.834 ft^3

Oxygen req. ft^3/min = (16.08)(11.834) = 190.29 ft^3/min

- For Combustion Process Use:

Fuel - .783 gal/min

Oxygen - 190.29 ft^3/min

- Volume of Products of Combustion:

Assume combustion properties - 4300°F (4760°R)

- 240 psi (254.7 psia)

Assume Univ. Gas Const., R_0 - 1545

$$V = \frac{wR_0T}{p}$$

$$V = \left(\frac{1.42}{18} + \frac{3.09}{44}\right)\left(\frac{(1545)(4760)}{(254.7)(144)}\right)$$

$$V = 29.87 \text{ ft}^3/\text{lb of fuel}$$

From above, 4.58 lbs fuel used per min

Therefore, (29.87)(4.58) = 136.8 ft^3/ min

As the volume of combustion gases rises through the well bore, it will cool, be under less hole pressure, and enter into larger well bore areas. Thus it will undergo a volume change. This will be computed as follows:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Because, as previously noted, the question of true bore hole temperature has been raised, this computation shall be made considering both sets of temperatures.

Assume - P_1 = 240 psi (254.7 psia)
- T_1 = 4300°F (4760°R)
- V_1 = 136.8 ft^3
- Well bore diameter increase not considered
- Temperature T_2 obtained from Curves C and D, Figure 20

Volume Change - See Table 7

COMBUSTION PRODUCTS

100% OXYGEN/FUEL

VOLUME CHANGE

Table 7

Hole Depth	Curve C				Curve D			
	Temperature T_2		Pressure P_2 (1)	Volume V_2	Temperature T_2		Pressure P_2 (1)	Volume V_2
ft	°F	°R	psia	ft^3	°F	°R	psia	ft^3
2,000	80	540	40	126	158	618	40	144
4,000	100	560	50	104	216	676	50	126
6,000	130	590	65	84	266	726	65	104
8,000	155	615	80	71	324	784	80	91
10,000	180	640	100	60	392	852	100	79
12,000	200	660	120	51	468	928	120	72
14,000	260	720	145	46	554	1014	145	65

(1) Ref.: - Angel, R. R., "Volume Requirements for Air and Gas Drilling", SPE-TP-4679, Oct., 1957.
- All pressure values doubled to compensate for heavier chip weight.

Volume of Steam - 100% Air/Fuel and 100% Oxygen/Fuel Processes

It will be assumed that the flow rate of water is the same in both processes. Thus the volume of steam produced will be dependent upon hole pressure and temperature. Because, as previously noted, the question of hole temperature has been raised, this computation shall be made considering both sets of temperature.

Assume - Flow rate of water = 20 gpm

- 1 gal water = 8.357 lbs
- Flow rate = (20)(8.357) = 167.1 lbs/min
- Temperature will be obtained from Curves C and D, Figure 20

Volume of Steam - See Table 8

VAPORIZATION OF COOLING WATER

VOLUME OF STEAM

Table 8

Hole Depth ft	Hole Press. psia	Saturation Temp.[1] °F	Curve C			Curve D		
			Hole Temp. °F	Sat. Vapor[2] ft^3	Steam Vol.[3] ft^3	Hole Temp. °F	Sat. Vapor[2] ft^3	Steam Vol.[3] ft^3
2,000	40	268	80	-	-	158	-	-
4,000	50	281	100	-	-	216	-	-
6,000	65	298	130	-	-	266	-	-
8,000	80	312	155	-	-	324	5.6	936
10,000	100	328	180	-	-	392	4.9	819
12,000	120	341	200	-	-	468	4.5	752
14,000	145	355	260	-	-	558	4.0	668

Ref: (1) Keenan, J. H., and Keyes, F. G., Thermodynamic Properties of Steam, John Wiley & Sons, 1951.

(2) Specific Vol. of 1 lb. of Saturated Vapor

(3) Steam Vol. = Specific Volume x Water Flow Rate (167.1 lbs/min)

Volume of Boost Air

The volume of boost air required to effectively lift the rock chips to the surface will be determined by subtracting the produced volumes of steam and combustion gases from the minimum theoretical volumes of required circulation air. The minimum volumes are based on the equation:

$$Q = Q_0 + N \times H$$

Q = Req. SCFM

Q_0 = Base SCFM

N = Drilling Rate Factor

H = Depth Factor

This equation corrects the assumed standard air lift velocity of 3000 ft/min to compensate for drilling penetration rate increases and hole depth. In holes to 10,000 ft. depth and larger than 6-1/4 in., the equation may have an error of up to 7%. When using this equation, hole diameter must also be considered.

In view of the above, and the hole configuration of Figure 17, boost air volumes were determined as noted in Table 9. Table 9 evaluates boost air for both generic well models and for two different sets of conditions for each model. Case 1 relates to a 100% air/fuel system and well bore temperatures of Curve C, Figure 20. Case 2 relates to a 100% oxygen/fuel system and well bore temperatures of Curve D, Figure 20. Hole characteristics are defined for each well model. These characteristics include well diameter for both cased hole and open hole conditions, and circulation air required. Circulation air is divided into two columns. The first column states air requirements for both the cased and open hole diameters of approximately 12.5 in. The second column relates to air requirements for both the cased

BOOST AIR VOLUME REQUIRED

Table 9

Hole Characteristics					Case 1						Case 2					
Condition	Depth	Press.[1]	Circ. Air[1] Required		Hole Temp.	Steam Vol.	Comb. Gas Vol.	Total St. & Comb.	Boost Air Required		Hole Temp.	Steam Vol.	Comb. Gas Vol.	Total St. & Comb.	Boost Air Required	
	ft	psia	ft^3	ft^3	°F	ft^3	ft^3	ft^3	ft^3/min	ft^3/min	°F	ft^3	ft^3	ft^3	ft^3/min	ft^3/min
• Generic Well Model No. 1																
	2,000	40	1,960		80	-	319	319	1,641		158	-	144	144	1,816	
12.61" ID Cas.-2,493'																
	4,000	50	2,220		100	-	264	264	1,956		216	-	126	126	2,094	
	6,000	65	2,480		130	-	214	214	2,266		266	-	104	104	2,376	
	8,000	80	2,740		155	-	181	181	2,559		324	936	91	1,027	1,713	
	10,000	100	3,000		180	-	151	151	2,849		392	819	79	1,598	1,402	
12.51" Hole-11,616' 8.83" ID Cas.-11,578'																
	12,000	120		2,167	200	-	130	130		2,037	468	752	72	824		1,343
	14,000	145		2,395	260	-	117	117		2,278	554	668	65	733		1,662
8.75" Hole-15,289'																
• Generic Well Model No. 2																
	2,000	40	1,960		80	-	319	319	1,641		158	-	144	144	1,816	
12.35" ID Cas.-2,552'																
	4,000	50	2,220		100	-	264	264	1,956		216	-	126	126	2,094	
	6,000	65	2,480		130	-	214	214	2,266		266	-	104	104	2,376	
	8,000	80	2,740		155	-	181	181	2,559		324	936	91	1,027	1,713	
	10,000	100	3,000		180	-	151	151	2,489		392	819	79	1,598	1,402	
12.23" Hole-10,791' 8.83" ID Cas.-10,374'																
	12,000	120		2,167	200	-	130	130		2,037	468	752	72	824		1,343
	14,000	145		2,395	260	-	117	117		2,278	554	668	65	733		1,662
8.75" Hole-13,933'																

(1) Ref.: Angel, R. R., "Volume Requirements for Air and Gas Drilling", SPE-TP-4679, Oct., 1957

and open hole diameters of approximately 8.8 in. In Case 1 and Case 2 boost air requirements are similarly stated. Steam and combustion gas volumes are taken from Tables 6, 7, and 8 as required.

Evaluation of Table 9 indicates that large volumes of boost air are required. In Case 1, the cooling water does not turn to steam because of the low hole temperature and moderate hole pressure that keeps the water below the required saturation temperature for steam. Thus the only lifting fluid available is the combustion gases. In Case 2, bottom hole temperatures and pressures are such that the water does turn to steam. However, above the 6000 ft. level these conditions fall below the saturation temperature for steam, and the steam condenses out. Under either condition, insufficient fluid volume is present even when considering the volume of combustion gases available to effectively lift the chips. Thus large volumes of boost air will be required. Considering the amount of boost air required, flame jet drilling, regardless of whether air or oxygen is used, can more accurately be described as a very complex form of air drilling.

It must be emphasized that the fluid volumes discussed above are minimum volumes. In addition, the volumes of steam and combustion products are based on numerous assumptions. Thus the results noted in Table 9 can only be considered general in nature and not definitive or exact.

Umbilical Hose Design

From previous sections of this report, the volumes of required fluids are estimated to be:

- 100% Air/Fuel System

Fuel	- .667 gal/min
Combustion Air	- 773 ft^3/min
Water	- 20 gal/min
Boost Air	- 2850 ft^3min

- 100% Oxygen/Fuel System

Fuel	- .783 gal/min
Oxygen (Gas)	- 190 ft^3/min
Water	- 20 gal/min
Boost Air	- 2376 ft^3/min

It should be noted that these volumes differ somewhat from those stated in Section IV B, System Specifications. In those specifications, the air volume for the 100% air/fuel system includes combustion air and boost air, but for a very shallow hole of smaller diameter. Thus the noted difference. In the 100% oxygen/fuel specification, the oxygen requirement is much higher. This is because the fuel characteristics are different from those used in the analyses of this report. Unfortunately the original specifications could not be fully used in these analyses because they did not contain sufficient information to determine boost air for the well models chosen, needed steam characteristics, etc. These differences are not considered significant with regard to the main thrust of this report.

The elements of the umbilical hose consist of:

- Combustion Air/Oxygen Line
- Water Line
- Fuel Line
- Electric Power Cable
- Electric Communication Cable
- Boost Air Line

These elements will be packaged into an umbilical according to Configuration B, Figure 26. Each element will be designed in accordance with the flow rates stated above and the design constraints previously discussed.

- Combustion Air/Oxygen Line

Consider: 2" ID hose

800 SCFM air @ 350 psi surface pressure

Pressure Drop in Hose:

$$P.\ D. = \frac{.625}{10^5} \times \frac{520}{P} \times \frac{(SCFM)^2}{d^{5.257}}$$

P = Abs. Pressure

d = Hose ID

$$P.\ D. = 1.49 \text{ psi}/100' \text{ of hose}$$

For 16,000 ft. of hose:

$$P.\ D. = (1.49)(160) = 239 \text{ psi}$$

Pressure at bottom of hose:

$$P = 350 - 239 = 111 \text{ psi}$$

- Water Line

The water line shall be designed so that a five minute water supply will be maintained in the hose at all times. This will limit the pressure head developed by the vertical column of water, and in turn lower the burst pressure requirements of the hose. Beyond a certain hole depth, this water column will not fill the hose completely. If the hole temperatures rise above the saturation temperature of the water, the water will start to vaporize at the top of the water column. When this happens, pressurization of the hose should be considered.

Consider: 1-1/4" ID hose

Pressure Drop:

4 psi/100' of hose @ flow rate of 20 gpm

Height of Water Column:

15.68 ft of hose holds 1 gal fluid
5 min of flow @ 20 gpm = 100 gal
1568 ft of hose holds 100 gal fluid
1568 ft = height of water column

Max Water Pressure = (1568)(.433) = 679 psi

- Fuel Line

The fuel line will be designed in the same manner as the water line, considering a five minute fuel supply and a pressurization system in the event the fuel starts to vaporize.

Consider: 7/8" ID hose

Pressure Drop:

2.7 psi/100' of hose @ flow rate of .8 gpm

Height of Fuel Column:

32 ft of hose holds 1 gal fuel
5 min of flow @ .8 gpm = 4 gal fuel
128 ft of hose holds 4 gal fuel

Max Fuel Pressure = (128)(.433)(.703) = 39 psi

• Electric Power Cable

The electric power cable is used to supply electric power for the burner electric ignition system and other down hole electric power needs, such as logging, burner rotation, etc. Cable to supply this type of application can be developed as needed. This cable is estimated to be 3/4" in diameter.

• Electric Signal Cable

This cable is used to provide a real time communications link between the surface equipment and the down hole equipment. This type of cable can be developed as needed. It is estimaed to be 3/4" in diameter.

• Outer Line (Boost Air)

As noted in Figure 26, Configuration B, boost air is transported in the annular area between the hoses and the outer or container hose of the umbilical. This outer hose will be similar to that produced by Coflexip of France. It will carry the tensile load seen by each of the connectors and thereby limit the tensile load of each of the internal hoses to that of the weight of each hose between the connectors. The ID of the hose will be 5" to allow sufficient space for the other internal hoses and cables.

The outer surface of the umbilical will be covered with a sacrificial material to compensate for the abrasive problem previously stated. In addition, oil field type rubber bumpers shall be used to keep the umiblical off the well wall as much as possible.

• Umbilical Dimensions

The internal hoses were chosen on the basis of providing internal diameter that would reduce flow friction as much as possible and thereby lower internal hose pressure. In addition, the hose outer diameter had to be large enough to provide sufficient burst strength and tensile load carrying capability. Considering these factors, a compilation of dimensions and weights involved in the design of the umbilical are stated in Table 10. Dimensions and weights were obtained from catalogs that listed hoses that approached the physical requirements needed. In no case were stock hoses found that met the necessary physical requirements of strength and temperature. Thus the hoses stated are only estimates of how the umbilical might be designed.

The umbilical design is further complicated by the fact that few if any hoses of the type needed are manufactured in 2000 ft. lengths. Discussion with manufacturers tends to indicate that this may be a very significant problem, particularly when cost is considered.

Another problem of significance is the design and development of the end connectors. As previously stated, past experience in the design of umbilical connectors has shown that this, too, will be a very difficult problem to overcome.

• Estimated Cost

The estimated cost of the umbilical is based on the cost of standard, off-the-shelf hoses, cables, etc. that approach the physical requirements of defined umbilical components. The actual cost of the umbilical components will probably be greater because of the manufacturing problems involved, tensile load carrying capabilities of the hoses, etc. It should also be noted that the outer line will vary in section cost because of the extra steel required for tensile strength in the upper sections.

UMBILICAL DESIGN CHARACTERISTICS[1]

Table 10

• Physical Dimensions

Component	ID in.	OD in.	Est. Wt. 100' lbs.	Temp. Rating °F	Bend Radius in.
Combustion Air/Oxygen Line	2	2-21/32	220	-40, +200	25
Water Line	1-1/4	2-5/32	320	-40, +200	18
Fuel Lne	7/8	1-15/64	46	-40, +200	7-3/8
Electric Power Cable	--	1/2	20	250	--
Electric Communication Cable	--	1/2	20	250	--
Outer Line (Boost Air)[2]	5	6-1/2	Var.	--	48

• Weight

Component	Section[3] I lbs.	Section II lbs.	Section III lbs.	Section IV lbs.	Section V lbs.	Section VI lbs.	Section VII lbs.	Section VIII lbs.	Total Weight lbs.
Combustion Air/Oxygen Line	4,400	4,400	4,400	4,400	4,400	4,400	4,400	4,400	
Water Line	6,400	6,400	6,400	6,400	6,400	6,400	6,400	6,400	
Fuel Line	920	920	920	920	920	920	920	920	
Electric Power Cable	400	400	400	400	400	400	400	400	
Electric Communication Cable	400	400	400	400	400	400	400	400	
Outer Line (Boost Air)[2]	77,000	77,000	77,000	82,000	87,000	92,000	97,000	102,000	
Connector Set (Male & Female)	100	100	100	100	100	100	100	100	
Total Weight	89,620	89,620	89,620	94,620	99,620	104,620	109,620	114,620	791,960

Notes: (1) All dimensions are estimates based on catalog information of similar components.

(2) Outer Line weights vary for each section due to the added strength characteristics of the upper sections compared to the lower sections. Standard, unstrengthened hose of this type weighs approximately 38.5 lbs. per foot.

(3) Each section is estimated to be 2000' long. Section I is the first section used in the drilling operation.

For purposes of this study, the estimated costs will be:

Outer Line (Boost Air) Cost Estimate

Section I	- $100/ft x 2000'	=	$ 200,000
Section II	- $100/ft x 2000'	=	200,000
Section III	- $100/ft x 2000'	=	200,000
Section IV	- $110/ft x 2000'	=	220,000
Section V	- $120/ft x 2000'	=	240,000
Section VI	- $130/ft x 2000'	=	260,000
Section VII	- $140/ft x 2000'	=	280,000
Section VIII	- $150/ft x 2000'	=	300,000
			$1,900,000

Umbilical Cost Extimate

Combustion Air/Oxygen Line:	
$6.18/ft x 16,000'	$ 98,880
Water Line:	
$17.61/ft x 16,000'	281,760
Fuel Line:	
$2.00/ft x 16,000'	32,000
Electric Power Cable:	
$0.20/ft x 16,000'	3,200
Electric Communication Cable:	
$0.20/ft x 16,000'	3,200
Outer Line (Boost Air):	
(from above)	1,900,000
Connectors:	
$1,000/set x 8	8,000
Total Cost	$2,327,040

Transportation Reels

The transportation reels provide a means for transporting the umbilical hose sections from one well location to another. The reels are mounted on skids so that they can be transported by truck and then left at the well site. Because of the truck transportation, the reels should be designed to conform as close as possible to state highway permit loading specifications. Loads that are dimensionally greater than state highway load specifications may require special highway routing because of underpass and bridge clearances, bridge capacities, etc.

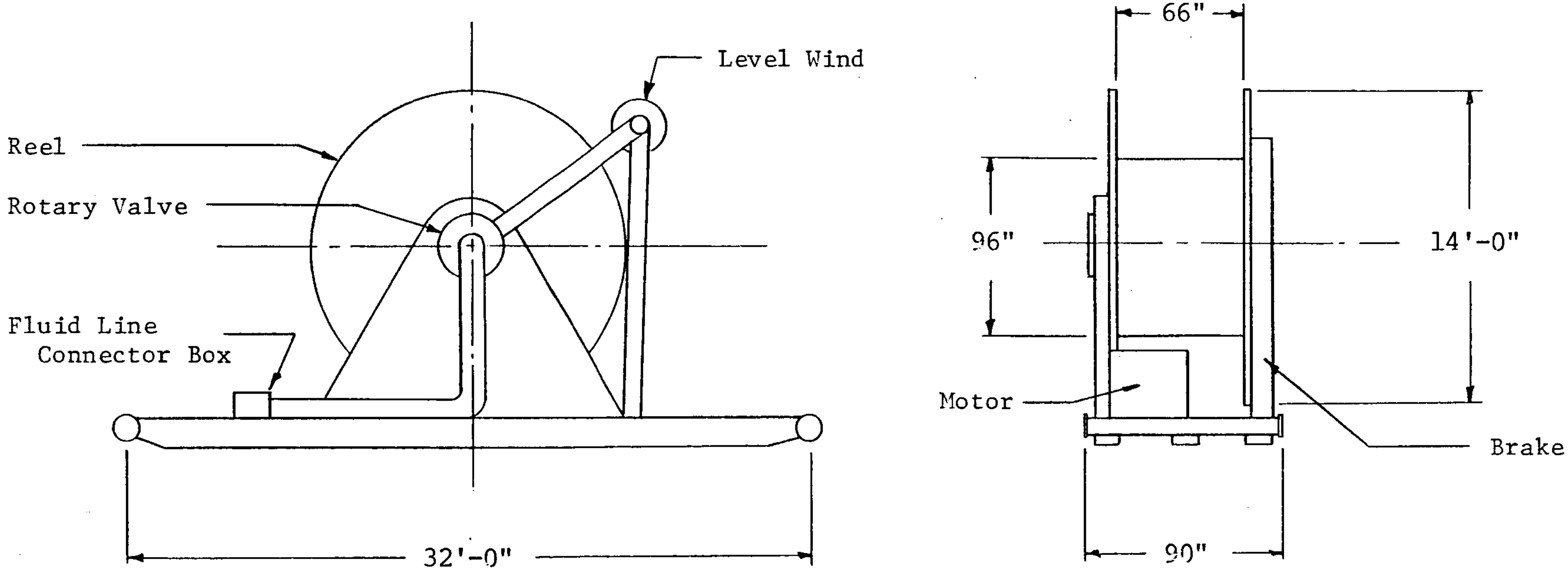
The reel skids must be designed to provide:

- Capacity - 2000 ft. of 6-1/2" OD umbilical with a 48" bend radius.
- Level wind system for controlled reeling.
- Power and braking system for reel rotation.
- Rotary valving and associated equipment to allow injection of down hole air/oxygen, water, fuel, power, and electrical communications into the reeled or moving umbilical.

To meet the above specifications, the approximate dimensions of the reel will be:

- Drum Diameter - 96 in. (min.)
- Drum Width - 66 in. (max.)
- Reel OD - 14 ft. (min.)
- Reel Skid Width - 90 in.

The reel skid will be designed essentially as noted in Figure 27. This design presents several problems, the first of which is a combined weight of skid and umbilical of approximately 120,000 to 150,000 lbs. The tractor-trailer system that moves this equipment must have a



Side View

End View
(w/o Level Wind)

TRANSPORTATION REEL

Figure 27

significant number of axles to reduce the load to an acceptable axle weight. Thus, the number of acceptable vehicles will be limited. An additional problem is also found in the overall diameter of the reel. A reel of this diameter, when skid mounted and placed on a trailer for transportation, will be well over the acceptable height limits for highway truck loads. Thus special routing will be required.

It may be possible to eliminate or reduce the significance of the above problems by reducing the length of the umbilical hose sections. If this was done, reel diameters and load weights could be reduced. This in turn would affect the umbilical design by requiring more connectors. It would also reduce tensile load requirements of all internal lines and cables, which may reduce umbilical cost. Well trip time would, however, increase because of the additional number of connections to be made.

Final design of these transportation reels should consider the above factors. Its relationship to other components cannot be ignored. Overall design of the transportation reels does not, however, appear to present any serious design problems.

Estimated Cost:

- Cost per Unit:

Skid Structure	$ 10,000
Reel	18,000
Motor and Brake	10,000
Level Wind	15,000
Valving, Piping, Cable, Controls	15,000
	$ 68,000

- Cost of 8 units: $544,000

Winching Mechanism

A mechanism to provide controlled movement of the umbilical into and/or out of the well bore is required. This device must be capable of gripping or attaching itself to the umbilical and yet allow the required controlled movement. It must be capable of handling a tension load of at least 850,000 lbs., which consists of the weight of the umbilical plus an overpull factor. In addition, the device must be securely mounted on the surface or attached to the conventional rotary rig sub-structure so that the weight of the umbilical, when hung in the well, does not physically move it.

There are several mechanisms that may be capable of performing this function if they were properly modified or redesigned. The first device is a pipe tensioning system, Figure 28, used to lay subsurface pipe offshore. Many of these machines are used successfully to lower pipe off the end of a pipe laying barge into the water. This system could be adapted to handling an umbilical. The overall weight of the umbilical would require the use of seven LPT-120 units. These seven machines would produce a surface system 243 ft. long and 22 ft. high.

The second system, Figure 29, is a device designed by a French company specifically for handling umbilicals. The system uses traction mechanisms to grab the umbilical and move it as required. Each traction module has a capacity of 80,000 lbs. Thus 11 units would be required. Each unit is 8 ft. wide, 8 ft. long, and weighs approximately 36,000 lbs. Eleven of these units would produce a surface system 88 ft. long and 8 ft. wide.

The third system, Figure 30, is a traction winch. This device is used for pulling in or paying out cable under load. Many of these devices have been used successfully for laying cable offshore or providing a tension load on a cable. The specific winch noted has a capacity of 53,000 lbs., and is approximately 17-1/2 ft. long and 11-1/2 ft. high. Modification of this device to handle an 800,000 lb. tension load is very questionable.

Although other systems that can perform this type of function may be available, no information was found on them. Thus it may be safe to state that no system capable of performing the function required in a reasonable and economic manner exists. Therefore, it will be necessary to modify one of the above systems, or a combination of the above systems, to develop a mechanism that will perform the stated function. Of the systems noted, the traction winch should be evaluated first, as there is little that can be done to change the basic concept of the other two systems and thereby reduce their overall size and complexity.

Considering the above factors, the winching mechanism presents a formidable design challenge. This problem should be solvable, but it will require some very creative work.

The cost of such a device is very questionable. The following estimation could be very low.

Estimated Cost: $1,000,000

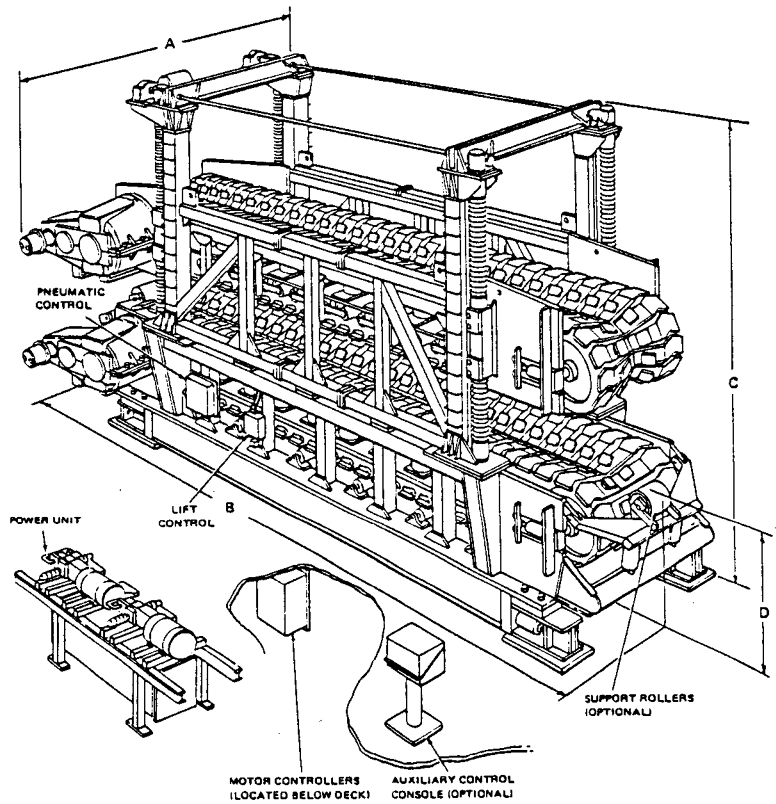
LPT SERIES PIPE TENSIONERS

MODEL NO.	MAX. TENSION	SPEED: RATED IN-HAUL/PAYOUT		SPEED: OPTIONAL* IN-HAUL/PAYOUT		PIPE SIZE – O.D. CONCRETE: RATED DIAMETER	PIPE SIZE – O.D. CONCRETE: MAX. DIAMETER**
LPT 40	40 000 LB 18 144 Kg	80 FPM/ 24 MPM/	80 FPM 24 MPM	120 FPM/ 37 MPM/	120 FPM 37 MPM	6" – 30" 152.mm – 762.mm	50" 1270.mm
LPT 80	80 000 LB 36 287 Kg	80 FPM/ 24 MPM/	80 FPM 24 MPM	120 FPM/ 37 MPM/	240 FPM 74 MPM	8" – 48" 203.mm – 1219.mm	72" 1829.mm
LPT 100	100 000 LB 45 350 Kg	120 FPM/ 24 MPM/	120 FPM 37 MPM	120 FPM/ 37 MPM/	240 FPM 74 MPM	8" – 48" 203.mm – 1219.mm	72" 1829.mm
LPT 120	120 000 LB 54 431 Kg	80 FPM/ 24 MPM/	120 FPM 37 MPM	120 FPM/ 37 MPM/	240 FPM 74 MPM	12" – 60" 305.mm – 1524.mm	84" 2134.mm

DIMENSIONS

MODEL	A NOT INCLUDING MOTOR PIPING	B INCLUDING OPTIONAL SUPPORT ROLLERS	C	D DIM. TO BOTTOM OF PIPE	WEIGHT***
LPT 40	124" 3149mm	264" 6706mm	168" 4267mm	66" 1676mm	110 000 LB 49 895 Kg
LPT 80-1.5	164" 4165mm	346" 8788mm	247" 6273mm	59" 1498mm	190 000 LB 86 182 Kg
LPT 100-1.5	164" 4165mm	384" 9754mm	247" 6273mm	59" 1498mm	215 000 LB 97 522 Kg
LPT 120	150-1/2" 3823mm	417" 10592mm	275" 6985mm	59" 1498mm	250 000 LB 113 400 Kg

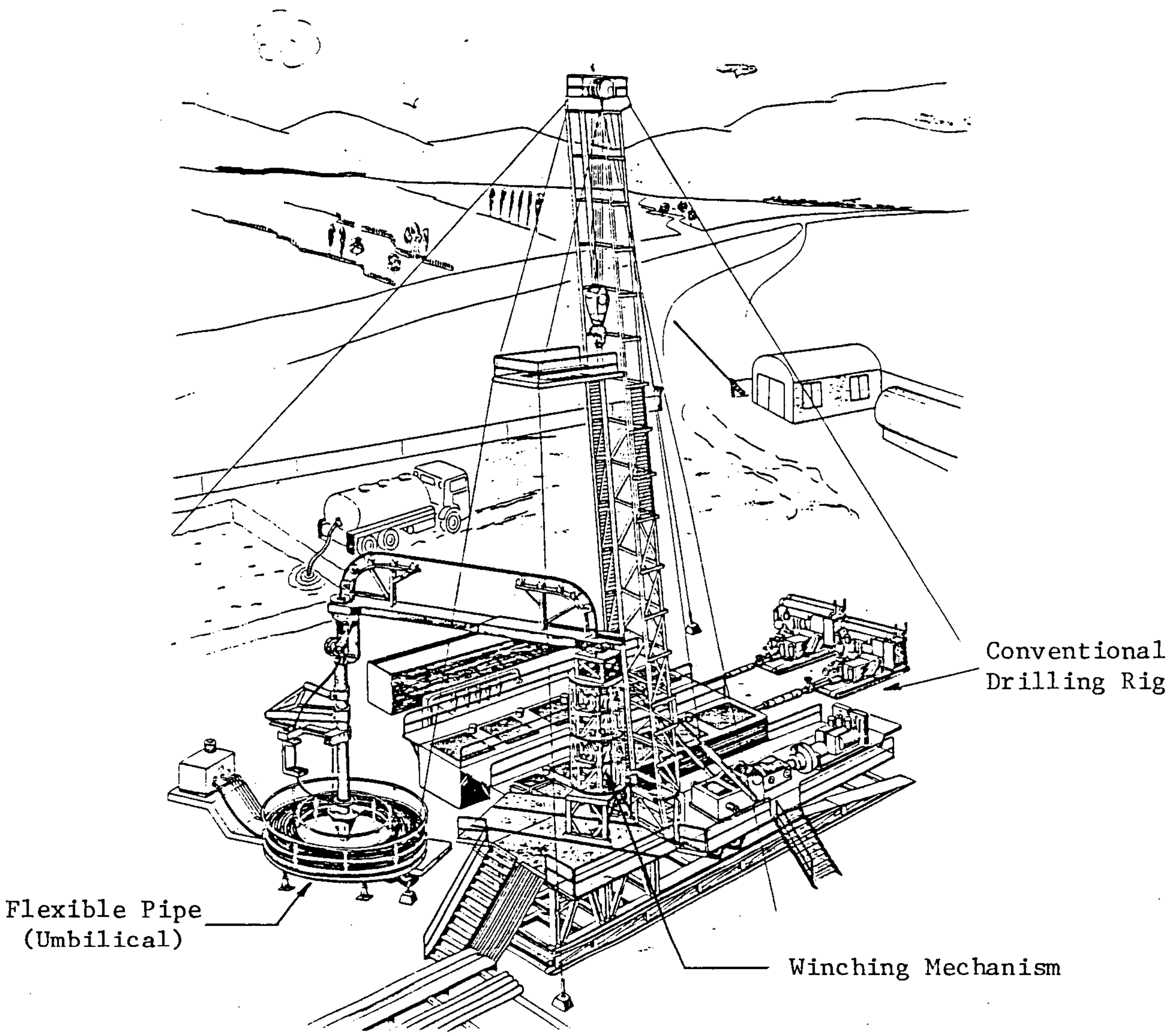
Dimensions and specifications subject to change without notice.
***Calculated weight includes power unit for rated speed.



PIPE TENSIONING SYSTEM

Figure 28

Ref.: Western Gear Corporation



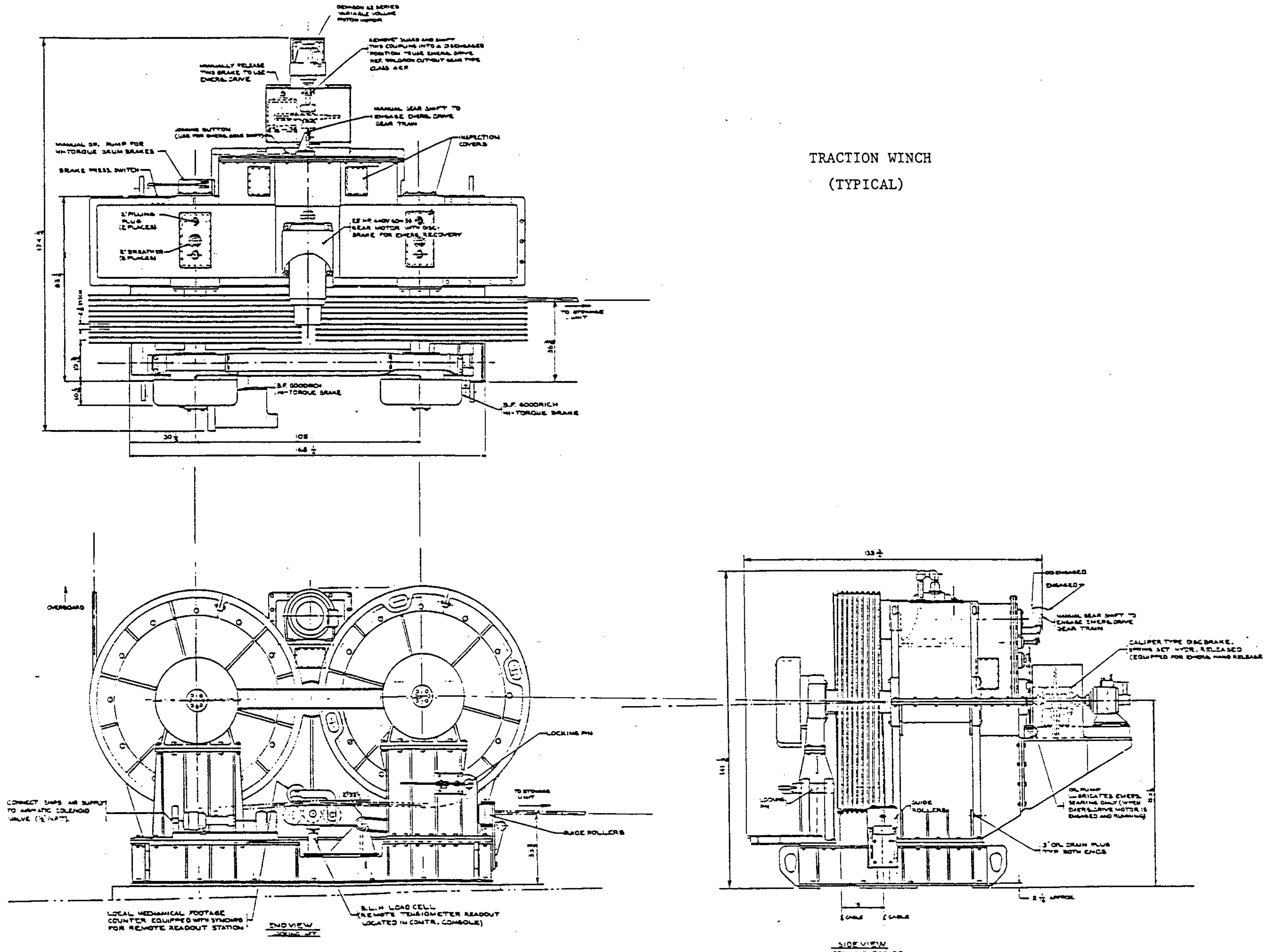
FLEXIBLE PIPE AND WINCHING MECHANISM

Figure 29

Ref.: Foraflex, S. A.

TRACTION WINCH

(TYPICAL)



Ref.: Western Gear Corporation

Figure 30

Auxiliary Components

The auxiliary components consist of the following subsystems:

Umbilical Guide Structure
Slip/Grab Mechanism
Fishing Tools

- Umbilical Guide Structure

This structure guides the movement of the umbilical from the end of the winching mechanism to a position that places it axially vertical above the well bore. This structure is required to assure the proper movement of the umbilical with regard to bend radii and positioning above the well bore.

The structure would be made from a series of steel lattice members that form a curved pathway lined with a series of rollers. The umbilical would be guided over these rollers and into the well bore. The design of this structure is quite simple and no design problems are anticipated.

Estimated Cost: $30,000

- Slip/Grab Mechanism

The slip/grab mechanism is used to grab and hold the umbilical in a fixed, static position in the well bore. It must be capable of holding the full weight of the umbilical in this position. The device would be placed directly above the well bore and concentric to the rotary table. It would be used to hold the umbilical in place in the event the winch mechanism failed or required repair when the umbilical is in the hole. In many respects, its function is similar to the slips on a conventional rotary rig. It differs from conventional slips, however, in the fact that it cannot use conventional slip inserts to grab the umbilical because the teeth of the insert would tend to rip, and possibly cause severe damage to, the umbilical. This is particularly true if the insert teeth were to cut the load carrying elements of the umbilical. Thus a mechanism that can quickly grab and hold the umbilical without damaging it must be designed. It is believed that this system can be designed using either a Kellums grip type device, or by placing a series of shoulders, which could be grabbed by the slip mechanism, on the umbilical. Other design concepts should also be reviewed. Considering the above, a design effort will be required to solve this problem. Although the device can probably be designed, a considerable creative effort will be required.

Estimated Cost: $75,000

- Fishing Tools

A set of fishing tools will be required for use with the umbilical. These tools will be used for working on the umbilical while it is in the hole. For example, the tools will be used to retrieve the umbilical in case part of it breaks off in the hole. Other functions would include freeing the umbilical in the event it gets stuck in the hole, or cutting off the lower part of the umbilical in case it cannot be freed from a stuck position. The difficulty in these types of operations is that the fishing tools must go down hole in the annular area between the umbilical and the well wall or the casing. In addition, they will probably be hung from a wire line, which will make this operation extremely difficult, if not impossible, to do. Further, space limitations in the annulus will make the design of the tools very difficult.

The design of good fishing tools is a problem that cannot be ignored. It would be foolish to build an umbilical-type drilling system without having these types of tools available. Failure to provide this capability could create extremely expensive problems. Thus, these tools must be designed and built. It should be noted that the French "claim" to have built a set of tools for their umbilical rig. However, the effectiveness of their tools is very questionable.

An estimated cost for the fishing tools is provided below. Because the design of these tools is unknown, the estimated cost could be very low or very high.

Estimated Cost: $200,000

3. Down Hole Burner System

The down hole burner system consists of the flame jet burner and the necessary controls and guidance equipment required for the burner to function properly. This combination of equipment will be assembled in a manner similar to that of Figure 31. The main components of the assembly are:

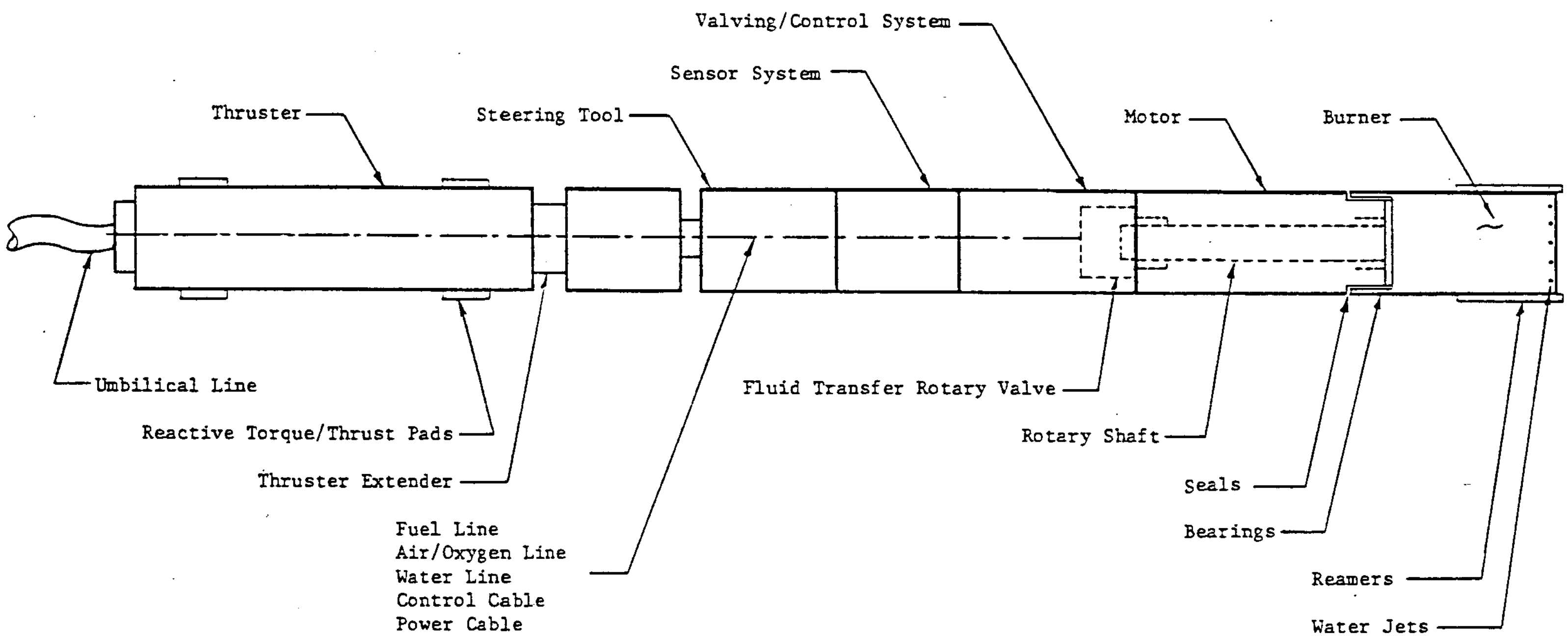
- Burner
- Motor
- Valving/Control System
- Sensor System
- Steering Tool
- Thruster

Most of these elements either exist in working form or have been conceptually designed. Thus, even though a design effort will be required to obtain the system in the configuration desired, there is a technology base on which to build.

The down hole burner system must be designed to meet the following specifications:

- Forward axial movement - 0 - 150 ft./hr.
- Directional movement - 0° - 3° in ½° increments
- Axial rotation - 0 - 50 RPM
- Rotary torque capability - 0 - 100 ft.lbs. (est. max.)

In addition to the above, the equipment must be designed to operate continually and effectively in ambient temperatures according to Curve D, Figure 20.



Downhole Burner System

Figure 31

Burner

The burner is the most essential element of the flame jet system. It produces the high temperature, high velocity flame jet by ignition of a mixture of fuel and an air/oxygen blend in a combustion chamber. The application of this flame jet exhaust against the face of the rock initiates the thermal spallation process.

The basic considerations in burner design consist of the thermodynamics of the combustion process, the design of the exhaust nozzle system, the exhaust flame geometry and relationship to the rock face, the cooling system design, and the materials used.

Considerable work has been done on the devices by both Browning Engineering and Linde. Both companies have produced numerous burners that have performed very well in the field. In fact, Linde burners have an estimated life of 300 hours. Thus, conceptual design of the burner will not be necessary. Design work will, however, be required to determine the effects of and design requirements for a variable air/oxygen and fuel mixture. Combustion chamber design, nozzle configuration, flame geometry, etc., must all be investigated to determine optimum configuration.

In addition to the above, work must be done to develop a reliable ignition system that will provide burner shut off or restart when the burner is deep in the hole. At present, both Browning and Linde systems are hand ignited on the surface. This concept cannot be used because of the problems of tripping a lit burner, particularly if the tripping process is stopped for some reason, while the lit burner is still inside the casing. Severe casing damage will occur.

To penetrate non-spallable rock veins or strata, Linde has encased its burner in a reamer shell as noted in Figure 13. On its lower edge, this shell has a series of hard metal lugs that are used to cut away the molten, non-spallable rock when the burner is rotated. The hole is also sized for clearance by this same rotational movement.

The burner also incorporates a water jet system that sprays water into the annular area between the reamer shell and the well wall. As previously stated, this water spray is used to quench the spalls, the well walls, and any molten material. It also assists in lifting particles to the surface. Prior to the water being sprayed in the annulus, the water is forced through a series of passages around the combustion chamber, thereby cooling it as illustrated in Figure 13.

As noted above, considerable work has been done in this design area. However, a design effort will be required to incorporate into these burner designs the features required for this rig program. No serious design problems are anticipated in this effort.

An estimated cost is provided below. This cost is based on the present cost of purchasing an off-the-shelf burner.

Estimated Cost: $5,000

Motor

The function of the motor is to provide an axial rotating or oscillating motion to the burner. It is claimed that this motion will assist the hole-making process, particularly if a multi-nozzle burner is used. In addition, the rotary motion assists the shell reamers in sizing the hole and scraping away molten rock. Because it is beyond the scope of this report to discuss the merits of rotation, it will be assumed that this motion is necessary.

Providing the motion is not a difficult design problem, particularly since the rotational torque is limited to a maximum of 100 ft.lbs. Numerous motors have been developed for down hole use. Thus motor configuration can be obtained. The only serious design problem anticipated is designing the motor for high temperature application. One possible solution to this problem is to water cool the motor by running the burner water lines around the motor. Another possible solution is to eliminate the electric motor completely and replace it with a small turbine operated by the flow of water from the burner water line. Water pressure will probably have to be increased to provide sufficient energy to meet the torque requirements. This in turn will require re-evaluation of the load capabilities of the water lines in the umbilical.

Regardless of the method chosen, it is believed that the motor can be built and the temperature problem resolved by proper application of water cooling techniques.

Estimated Cost: $30,000

Valving/Control System

The purpose of the valving/control system is to provide, as required, the necessary fluids for the combustion process. Combustion fluids must enter the combustion chamber at set flow rates and pressures. Flow pulsation problems, incorrect fluid ratios, etc., tend to lower the system efficiency. Thus, a means is necessary to provide these fluids in a controlled manner. Further, it will be necessary to start and stop the flow of these fluids as close to the burner as possible. All these functions require the use of a remote operated, down hole control system. The valving/control system provides this function. In many ways, this system is similar in function to a gas engine carburetor.

The design of this system is fairly simple. Most of these components are available today, and surface control can be obtained by two-way transmission of data between this system and the surface via the control cable.

Thus, no critical conceptual design problems are foreseen. The only problem of significance is the high temperature requirement. This problem might be solved by using the burner water to cool the various components in the same way considered for the motor.

A design effort will be required to develop this system. Extensive testing will be required to assure its proper operation at the design temperature levels.

Estimated Cost: $25,000

Sensor System

The sensor system obtains and transmits position and geological data to the surface. This data consists of azimuth, inclination, tool face orientation, down hole temperature and pressure, and any additional inspection or logging type information. The data is transmitted to the surface via the umbilical control cable.

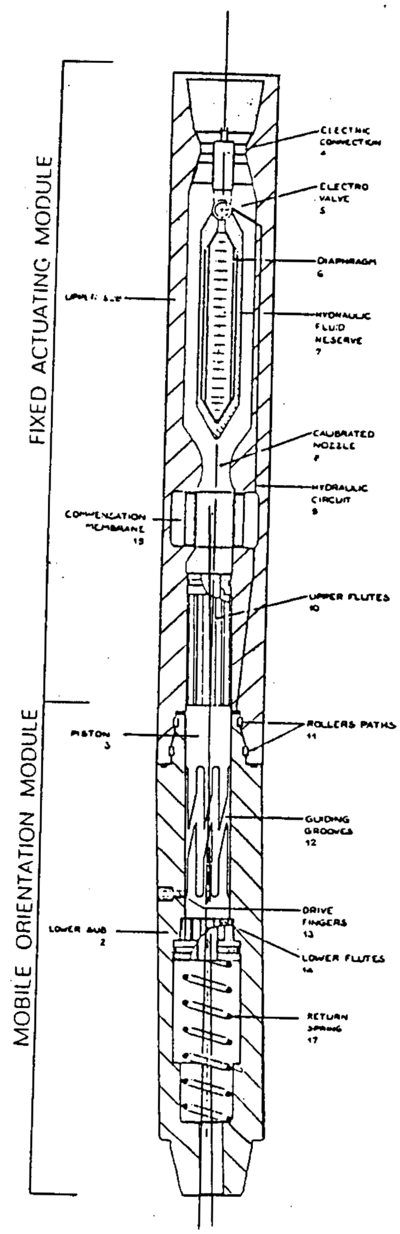
Instrumentation and sensors to obtain this type of information are available. Packaging the instruments into an acceptable down hole container does not appear to be difficult. The temperature requirement does, however, present a serious design problem. As suggested for the other down hole components, water cooling may be a possible solution to the problem. However, the amount of cooling the water system may be required to do may be greater than the capacity of the available water. Thus a cooling analysis of the total down hole burner system may be required as opposed to looking at individual subsystems.

Estimated Cost: $40,000

Steering Tool

Steering tools are down hole devices or systems used to change the lateral direction of the drilling bit or burner. This type of tool will be required if any directional drilling is required, or if there is any chance that the bit or burner will wander out of hole direction limitations when vertically drilling or burning.

A number of these devices have been designed and successfully used in the field. One design of specific interest for this project is a tool, built in France, that



STEERING TOOL

Figure 32

Ref.: SMF International

allows continual angle change from a remote position. This system uses an electrical signal, transmitted from the surface, to operate several valves, which in turn allows hydraulic pressure to operate or control the tool angle. An advantage of this type of system is that it permits surface visualization of the angular position.

To find a system that is compatible with the down hole burner system will require a design effort. Further, the system must be capable of operating at the elevated temperatures specified.

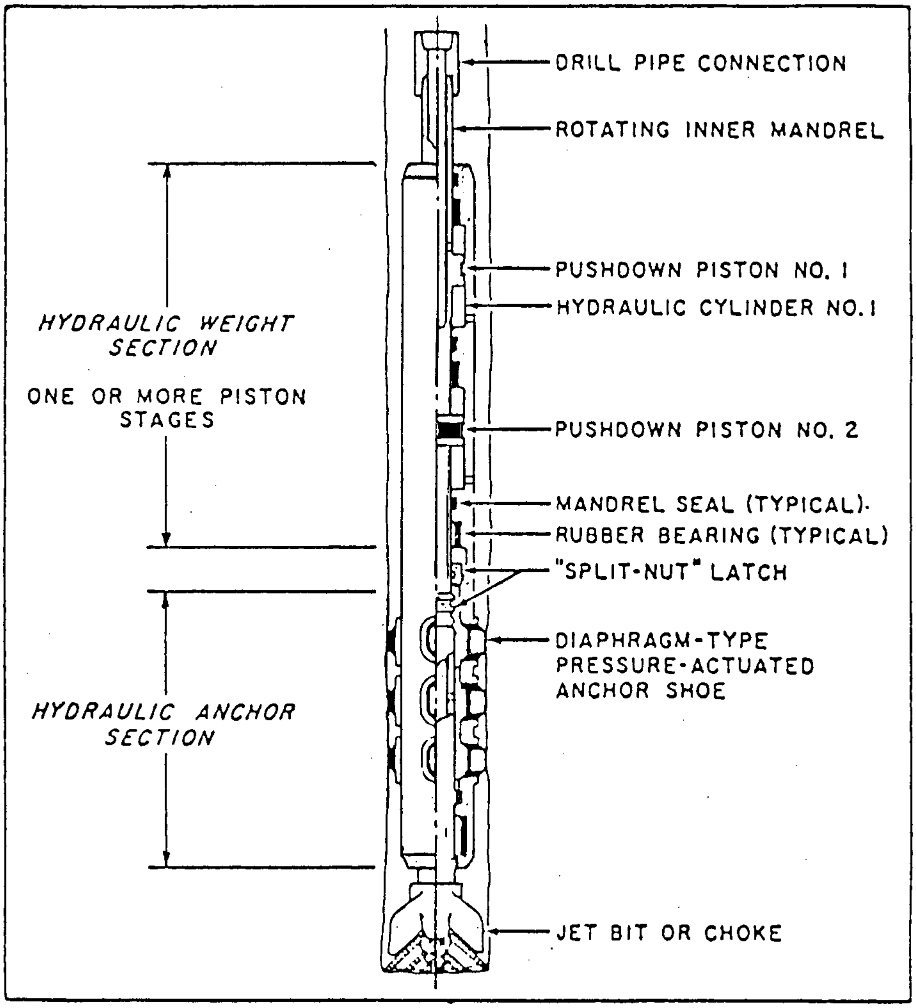
Because of the amount of work previously done in this area, it is believed that this problem can be resolved. The temperature requirement, however, could create some serious design problems.

Estimated Cost: $75,000

Thruster

Thrusters are down hole tools that place an axial load or thrust on the bit without the use of drill collars. The tool performs this function by grabbing the well wall and then applying an axial load to the bit. The well wall in turn absorbs the reactive thrust. These tools are primarily used for highly deviated or horizontal holes. Several of these devices have been built and used for experimental purposes.

For flame jet drilling, this tool will be used for a different purpose. Because the down hole burner system is hung from the umbilical, the reactive torque of the motor and burner reamers cannot be properly absorbed. In addition, there is no way to stabilize the umbilical so that the steering tool can operate from a set reference



THRUSTER

Figure 33

Ref.: Exxon Production Research Co.

point. Further, in a deviated hole, the burner will tend to lie on the lower side of the well bore, which will create directional problems. Thus, a means is needed to stabilize the burner with regard to the well axis and direction, and in addition, provide a way of absorbing reactive torque. The thruster, if designed properly, can provide these capabilities.

From an analytical view point, it should be possible to modify available thruster designs to provide the needed requirements of the down hole burner assembly. As in the case of all other components, temperature requirements will present serious problems that must be overcome.

Estimated Cost: $125,000

4. Control System

The control system incorporates the controls necessary to operate both the conventional rotary rig and the flame jet rig. Through this incorporation, both sets of controls are combined into one unified system. A schematic of this concept is noted in Figure 34.

The basic elements of this concept are:

- Driller's Control Console
- Subsystems
- Cables, Connectors, Junction Boxes

The driller's control console is the main operating station on the rig. It is located on the rig floor close to the rotary table. It contains the main controls for both the conventional and flame jet rigs.

The controls for the conventional drilling rig are similar to those of any standard drilling rig. No modification to these components is necessary except for the primary power distribution system, which must be redesigned to incorporate the ability to switch power, as required, from the conventional drilling system to the flame jet system.

The controls for the flame jet system will be designed similar to those used on Linde's JPM-5 rig. This system uses a computer to monitor and correct fluid flow rates so that optimum combustion conditions will be obtained. Because of the distance between the down hole burner system and the surface controls, the necessary pressure, temperature, and flow rate sensors must be placed in the down hole valving/control system. Signals from these sensors are transmitted to the surface computer where they are then analyzed. Signals for corrected control settings are then

CONTROL SYSTEM

CONVENTIONAL ROTARY/FLAME JET DRILLING RIG

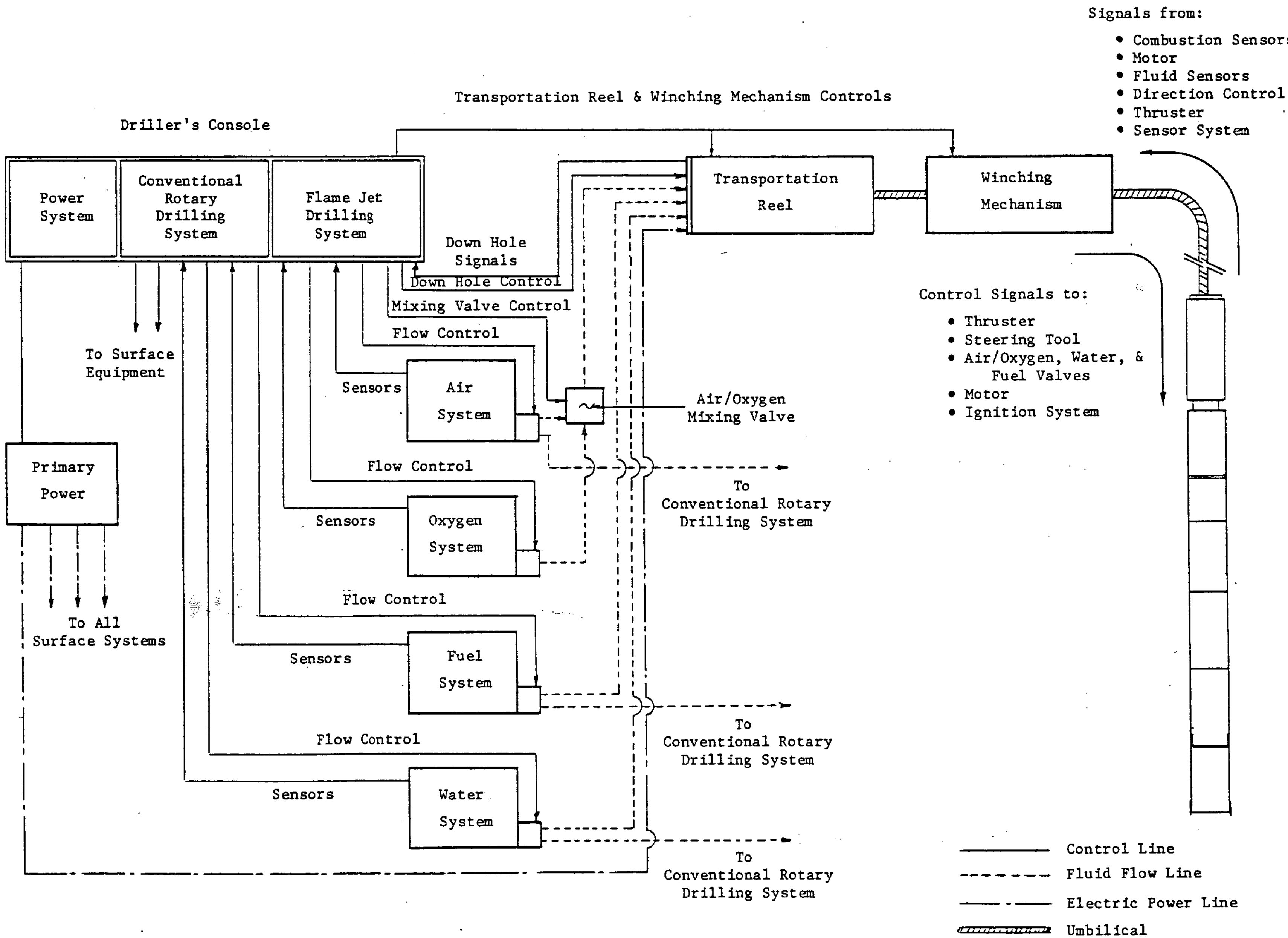


Figure 34

transmitted back down hole to the appropriate valves. Valve settings are automatically corrected as necessary.

In addition to fluid control, the surface controls also monitor and control burner feed rate, burner rotation, and burner angular movement. The concept used for the JPM-5 feed rate control (sensing of suspension cable weight) cannot be used because of the weight and length of the umbilical. Thus a new system must be developed. This system will require considerable study because movement of the winching mechanism and rotation of the transportation reels must be accurately coordinated with it. Thus a fairly complex set of controls will be required.

Burner rotation will be controlled by sensing its speed and adjusting the power input to the down hole motor module. Burner angular movement will be controlled by transmitting position data from the sensor system to a surface computer where it is compared to the required position data. Correction signals are generated and transmitted back down hole to the steering tool. Angular position of this tool is then corrected, which in turn corrects the burner position.

Other controls for monitoring and correcting surface systems will also be required. Data for these controls is obtained from the various surface subsystems. Sensors and controls are placed on these systems as required. This data is transmitted between the various systems by a series of cable connectors, etc.

Overall evaluation of the control system indicates that no major design problems should be encountered. However, a design program will be required.

Estimated Cost:

• Driller's Console		
Conventional Drilling Controls	-	$ 68,700
Flame Jet Drilling Controls		60,000
• Subsystems		40,000
• Cable, Connectors, Junction Boxes		25,000
	Total	$193,700

D. Rig Cost Summary

An estimated cost has been made for each of the various systems and components of the thermal spallation drilling rig. As previously stated, these costs are based, when possible, upon vendor information and engineering design judgement. Thus error in cost estimation is very possible.

In general, this error will be limited to the flame jet drilling equipment. Further, this error will probably be manifested in under-estimating component cost. Therefore, it can be stated that in all probability the cost of the conventional drilling system is fairly accurate, while the cost of the flame jet rig may be too low. An error factor of as much as 10% to 15% may be involved in the flame jet rig cost.

A tabulation of all costs involved is noted in Table 11.

It must again be emphasized that these costs are based on the assumption that the parts can in fact be designed and that they will operate efficiently and reliably. This assumption must be understood because of the severe design problems involved in many of the components of the flame jet rig.

THERMAL SPALLATION DRILLING RIG

COST SUMMARY

Table 11

A. System/Component Cost:		
1. Surface System		
• Conventional Drilling Modules		
Mast, Substructure and Accessories	$ 800,000	
Drawworks and Accessories	415,000	
Rotary and Traveling Equipment	260,000	
Mud Pump and Components	840,000	
Drill String	770,000	
BOP	325,000	
Handling Tools	92,000	
Miscellaneous	50,000	
• Flame Jet Drilling Modules		
Oxygen System	15,000	
• Common Modules		
Air System	745,850	
Water System	37,000	
Primary Power System	1,200,000	
Fuel System	13,000	
Miscellaneous	115,000	$ 5,677,850
2. Umbilical System		
• Umbilical	2,327,000	
• Transportation Reels	544,000	
• Winching Mechanism	1,000,000	
• Auxiliary Components		
Umbilical Guide Structure	30,000	
Slip/Grab Mechanism	75,000	
Fishing Tools	200,000	4,176,040
3. Down Hole Burner System		
• Burner	5,000	
• Motor	30,000	
• Valving/Control System	25,000	
• Sensor System	40,000	
• Steering Tool	75,000	
• Thruster	125,000	300,000
4. Control System		
• Driller's Console		
Conventional Drilling Controls	68,700	
Flame Jet Drilling Controls	60,000	
• Subsystems	40,000	
• Cable, Connectors, Junction Boxes	25,000	193,700
5. System Rig Up, Test, Rig Down		450,000
Total System Component Cost		$10,797,590
B. Specific Drilling System Cost:		
1. Conventional Rotary Drilling System Cost		$ 5,247,600
2. Flame Jet Drilling System Cost		5,549,990
Total System Cost		$10,797,590

VII. THERMAL SPALLATION DRILLING RIG OPERATION CHARACTERISTICS

The thermal spallation drilling rig is theoretically designed to drill any type of well in any type of geology. This can be done by using the conventional rotary drilling capability for all nonspallable rock drilling and the flame jet rig for spallable rock drilling. The conventional drilling rig will also be used to perform all casing operations and to drill through all cement placements. Flame jet operations can not be used on cement placements because some of the cement may still be inside the casing. Use of a flame jet inside the casing can result in extensive damage to the casing.

Control of conventional rig operations will be performed in the normal manual mode of operation with due consideration given to penetration rate, bit RPM, weight on bit, etc. Hole deviation will be controlled by using the proper down hole assemblies associated with drill pipe rotation or down hole motor rotation operations.

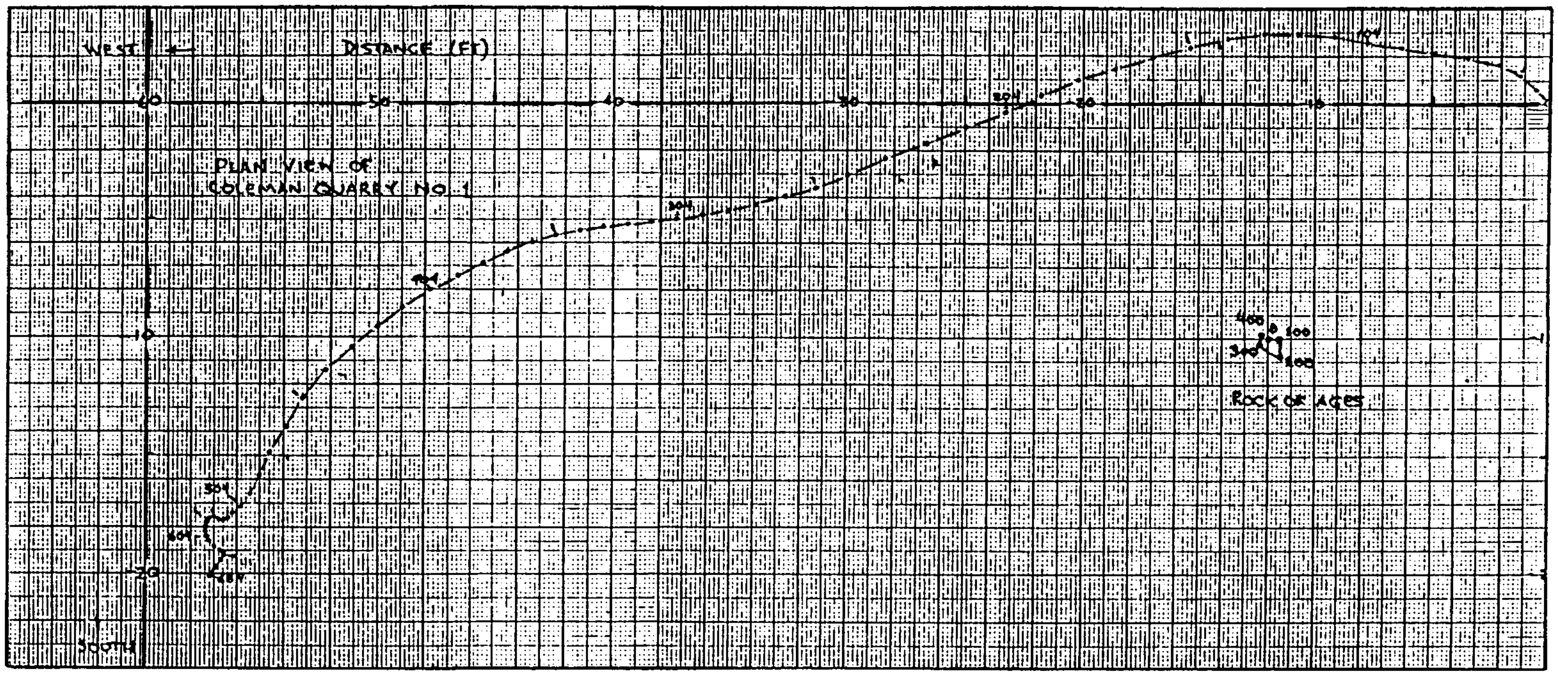
Conversely, flame jet drilling will be controlled in a more automated way because of the system capability to maintain two-way communication with the down hole equipment. This communication capability provides many advantages for the rig. Feed rate is an example of this. Flame jet drilling experience indicates that there is an optimum stand-off distance between the burner and the bottom of the well. Thus, feed rate is dependent upon the speed with which the rock will spall, or the speed with which hole is made. Maintaining feed rate, however, requires coordination between the feed rate sensing mechanism, the winching mechanism, and the transportation reels. This coordination can be further enhanced by the automation capability.

Hole gauge, or consistent hole clearance, must also be maintained because of the importance of providing a consistent annulus between the casing and the well wall for purposes of cementing. Further, a minimum hole gauge is required to ensure the ability to put casing in the well, or to prevent the burner from becoming jammed in the well.

Hole gauge is probably dependent upon feed rate, type of rock being penetrated, jet temperature, and exhaust mass velocity characteristics. Burner rotation may also be important to this because of the angular position of the burner nozzles. Because the interrelationships of these characteristics are not well understood, research is this area will be required.

As noted, burner rotation may be involved in maintaining constant hole gauge. Linde uses burner rotation to maintain minimum hole gauge. When the burner is rotated, the ribs and reamer lugs on the burner water jacket will clear away non-spallable material and/or fused material that has been softened by the flame jet. Further, the torque generated by this clearing action is used to assist in determining the required feed rate. If the torque is too high, as might be created by a tight hole or too much rock to be cleared away, the feed rate will be slowed down so that more spallation action will occur. Considering the above factors, burner rotation appears to be important in maintaining consistent hole gauge and drilling operations. More research is required in this area.

Capability to maintain required hole angle, whether vertical or deviated, is extremely important. Figure 35 indicates hole deviation in the two deepest flame jet holes drilled by Browning Engineering. Browning believes the hole divergence at the Coleman Quarry was due to the desire to drill as fast as possible. During that drilling operation, the burner was placed close to the bottom of the hole and little side clearance was maintained. In the other hole, penetration rate was reduced and a large side clearance maintained. The



Coleman Quarry: Maximum Deviation - 68' West & 20' South

Rock of Ages Quarry: Maximum Deviation - ½' East & 1' South

WELL DEVIATION CHARACTERISTICS

Figure 35

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A TECHNICAL AND ECONOMIC EVALUATION
OF
THERMAL SPALLATION DRILLING TECHNOLOGY

VOLUME IV

CORRESPONDENCE AND REPORTS

ASSOCIATED PATENTS

Patent No.	Date of Issue	Inventors	Assignee	Title
604,330	05/17/98	G.F. Kibling		Mining Apparatus for Frozen Soil
1,532,826	09/12/21	R. Lessing		Treatment of Coal
1,856,560	05/03/32	H.W. Jones		Torch Head
• 2,286,191	06/16/42	R.B. Aitchison C.J. Burch C.W. Swartout	Linde Div., UCC *	Mineral Piercing & Cutting
2,286,192	06/16/42	R.B. Aitchison G.H. Smith C.W. Swartout	Linde Div., UCC	Mineral Piercing & Cutting
2,327,482	08/24/43	R.B. Aitchison C.W. Swartout V.C. Williams	Linde Div., UCC	Mineral Cutting & Piercing
2,327,496	08/24/43 Re-issued 01/20/48	C.J. Burch	Linde Div., UCC	Method of and Apparatus for Working Mineral Materials and the Like

Notes:

* UCC -- Union Carbide Corporation
• Copies of patents included in this report

Patent No.	Date of Issue	Inventors	Assignee	Title
2,327,498			Linde Div., UCC	
2,327,508			Linde Div., UCC	
2,356,196	08/22/44	M.H. Barnes C.J. Burch W.G. Edwards	Linde Div., UCC	Blowpipe Apparatus
2,426,688	09/47	Higgs		Thermally Forming a Cavity in a Body of Mineral Matter
2,548,463	04/10/51	R.H. Blood		Thermal Shock Drilling Bit
2,628,817	02/17/53	R.O. Wyland, Jr.	Linde Div., UCC	Rock Piercing Blowpipe
2,633,332	03/31/53	J.J. Murphy J.M. Gaines E.L. McCandless	Linde Div., UCC	Flame Process
2,655,909	10/20/53	R.B. Aitchison H.L. Hicks J.R. Craig	Linde Div., UCC	Flame Finishing of Granite Surfaces
2,675,993	04/20/54	G.H. Smith W.J. Mitchell	Linde Div., UCC	Method and Apparatus for Thermally Working Minerals and Mineral-Like Materials
2,675,994	04/20/54	G.H. Smith B.M. Higginbotham W.J. Mitchell J.J. Calaman	Linde Div., UCC	Thermal Mineral Piercing Method and Apparatus
2,679,381	05/25/54	S.H. Royer A.J. Miller R.F. Hinschlager	Linde Div., UCC	Thermal Rock Piercing Apparatus with Automatic Control

Patent No.	Date of Issue	Inventors	Assignee	Title
2,693,937	11/09/54	R.O. Wyland, Jr.	Linde Div., UCC	Rock Piercing Blowpipe
2,694,550	11/16/54	R.B. Aitchison G.H. Smith	Linde Div., UCC	Churn Drill for Thermal Rock Piercing
2,712,351	07/05/55	D.W. Roth W.J. Mitchell	Linde Div., UCC	Method of Operating an Internal Combustion Blowpipe
2,738,162	03/13/56	R.B. Aitchison	Linde Div., UCC	Method and Apparatus for Forming Blastholes in Rock
2,745,346	05/15/56	R.B. Aitchison S.B. Kirk	Linde Div., UCC	Method of Charging Holes with Explosives
2,772,632	12/04/56	R.B. Aitchison J.J. Calaman	Linde Div., UCC	Blasting of Rock Bodies
2,781,754	02/19/57	R.B. Aitchison D.H. Fleming, Jr. H.V. Inskeep R.E. Armstrong, Jr.	Linde Div., UCC	Thermal Texturing of Rock
2,794,620	06/04/57	C.S. Arnold J.J. Calaman C.A. Napiorski D.H. Fleming, Jr.	Linde Div., UCC	Rock Piercing Blowpipe
2,827,112	03/18/58	H.V. Inskeep	Linde Div., UCC	Flame Blasting and Apparatus Therefor
2,859,939	11/11/58	W.M. Petrell		Rotary Drive Bushing
2,882,016	04/14/59	R.B. Aitchison G.H. Smith	Linde Div., UCC	Thermal Mineral Piercing Employing a Free Suspension Blowpipe
2,882,017	04/14/59	C.A. Napiorski	Linde Div., UCC	Rock-Piercing Method and Blowpipe

Patent No.	Date of Issue	Inventors	Assignee	Title
2,896,914	07/28/59	M.A. Ryan		Thermal Drill and Drilling Process
2,920,691	01/12/60	J.B. Henwood S.C. Wood		Burner
2,930,276	03/29/60	G.H. Smith W.J. Mitchell	Linde Div., UCC	Charging Blast Holes with Explosive
• 2,935,303	05/03/60	S.J. Royer A.J. Miller J.J. Calaman	Linde Div., UCC	Thermal Rock Piercing Control Apparatus
2,976,941	03/28/61	W.B. Horton		Method for Thermal Rock Piercing
2,990,653		Browning	Browning Engr. Inc.	Method and Apparatus for Impacting a Stream at High Velocity Against a Surface to be Treated
3,019,004	01/30/62	J.F. Vasselin		Method and Apparatus for Flame Cutting Mineral Bodies and Other Materials
3,024,874	05/15/62	N.L. Emmons J.P. Karpuk		Blow Torch Fuel and Method of Burning Same
3,027,447	07/62	Browning Harrington	Browning Engr. Inc.	Electric Arc Torch
3,045,766	07/24/62	D.H. Fleming, Jr.	Linde Div., UCC	Suspension Type Rotary Piercing Process and Apparatus
3,064,572	11/20/62	R.B. Aitchison		Method of and Means for Providing a Charge of Water-Sensitive Explosive in Blast Hole
3,093,197	06/11/63	D.C. Freeman, Jr. J.A. Sawdye	Linde Div., UCC	Method and Apparatus for Thermally Working Minerals and Mineral-Like Materials
3,103,251	09/10/63	J.A. Browning	Browning Engr. Inc.	Flame Cutting Method

Patent No.	Date of Issue	Inventors	Assignee	Title
• 3,116,798	01/07/64	F.R. Job, Jr.	Linde Div., UCC	Rock Piercing Blowpipe Having Internal Combustion Chamber
3,122,212	02/25/64	B. Karlovitz		Method and Apparatus for the Drilling of Rock
3,152,651	10/13/64	S.L. Ross		Excavating Apparatus and Method (Steam)
3,152,652	10/13/64	R.H. Murray W.L. Wilcox		Jet Piercing Blowpipe and Tooth Lug Therefor
3,160,536	12/08/64	R.B. Aitchison	Linde Div., UCC	Blasting Explosive
3,182,734	05/11/65	R.W. Scott		Fusion Piercing or Drilling Machine
• 3,205,953	09/14/65	F.G. Ferrabee	Can. In. Rand Co. **	Apparatus for Thermal Drilling
• 3,207,238	09/21/65	T.O. Davidson W.P. Atkinson	Bucyrus-Erie Co.	Thermal Piercing Control
3,207,241	09/21/65	W.J. Neilson		Jet Bits
3,208,674	09/28/65	F.M. Bailey		Electrothermal Fragmentation
3,211,242	10/12/65	J.A. Browning		Method of Flame Working Materials
3,212,592	10/19/65	H.C. Rolseth C.S. Arnold W.G. Kunz	Linde Div., UCC	Thermal Mechanical Mineral Piercing
3,224,486	12/21/65	L.B. Geller E.R. Mitchell		Method and Apparatus for Producing Air-Fuel Flames of Sonic and Supersonic Velocities
3,255,802	06/14/66	J.A. Browning		Method and Apparatus for Producing Flame Jet and Controlling Temperature and Flame Stability of Same

** Can. In. Rand Co. -- Canadian Ingersoll-Rand Company, Ltd.

Patent No.	Date of Issue	Inventors	Assignee	Title
3,322,213	05/30/67	C.S. Arnold H.C. Rolseth	Linde Div., UCC	Thermal Mechanical Mineral Piercing
• 3,344,870	10/03/67	W.V. Morris	Hughes Tool Co.	Reamer for Jet Piercer
3,363,661	01/16/68	W.B. Horton		Apparatus for Producing a Flame Jet by Combusting Counter Flow Reactants
3,373,306	03/12/68	B. Karlovitz		Method and Apparatus for the Control of Ionization in a Distributed Electrical Discharge
3,376,098	04/02/68	R.C. Pryor		Two-Chamber Burner and Process
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3,385,387			Linde Div., UCC	
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3,387,784	06/11/68	B.G. Ward, Jr.		Burner for Fluid Fuels
3,422,911	01/21/69	J.L. Dussourd		Method and Apparatus for Flame Working Spallable Material
3,464,506	09/02/69	A.M. Moyer W.R. McCarthy W.M. Petrell		Blower System for Jet Piercers
3,481,648	10/02/69	R.H. Kohler	Linde Div., UCC	Multiple Flame Channeling Method
3,482,640	12/09/69	J.A. Browning		Blast Hole Drilling Method
3,589,351	06/29/71	W.E. Shoupp		Cutting of Rocks, Glass and the Like
3,704,914	12/05/72	R.A. Fletcher, Jr.		Method of Fluid Jet Cutting for Materials Including Rock and Compositions Containing Rock Aggregates

Patent No.	Date of Issue	Inventors	Assignee	Title
• 3,792,741	02/19/74	R.B. Hopler, Jr.	Hercules, Inc.	Jet Spalling Assembly and Drill-Spalling Rig
• 3,835,937	09/17/74	Z. Hokao T. Shibata S. Yasukabe	TKKK *	Drilling and Cutting Submarine Rocks
• 3,870,111	03/11/75	R.M. Tuomela G.W. Schroeder R.O. Mattila	Reserve Mining Co.	Feed Rate Control for Jet Piercer
• 4,051,909	10/04/77	W. Baum	PEI Inc. **	Turbine Drill for Drilling at Great Depths
• 4,066,137	01/03/78	H. Frankle W. Baum	PEI Inc.	Flame Jet Tool for Drilling Cross-Holes
4,073,351	02/78	W. Baum	PEI Inc.	Burner for Flame Jet Drill
4,099,584	07/78	H. Frankle W. Baum	PEI Inc.	Flame Jet Tool for Burning to Great Depths

* TKKK -- Tobishima Kensetsu Kabushiki Kaisha

** PEI Inc. -- Process Engineering International, Inc.
Flame Jet Partners Ltd.

REPORT 2

A TECHNICAL AND ECONOMIC EVALUATION
OF
THERMAL SPALLATION DRILLING TECHNOLOGY

October 8, 1984

For

Sandia National Laboratories
Albuquerque, New Mexico

By

Resource Technology, Incorporated
4555 South Harvard Avenue
Tulsa, Oklahoma 74137

TABLE OF CONTENTS

ABSTRACT

In the initial study of flame jet drilling systems, it was noted that the design concept had not only significant economic advantages, but also severe technical problems when using an umbilical type system. Because of the economic advantages, Los Alamos National Laboratories conceived a new and different design approach to this problem. The purpose of this study is to economically and technically evaluate this new approach.

The methodology used in this study is similar to that used in the original study in that each component of the system was technically evaluated and then costed. This data was then applied to a computer model to evaluate the economic potential of the system.

The results of this study indicate that this new design sharply reduces the cost of drilling operations below 3200 feet when drilling a 15,000 foot hole. Cost reductions range from 45% to 49%, depending upon the type of equipment used. From a technical viewpoint, the concept appears viable. Although no severe technical problems are envisioned, it is strongly recommended that the system be thorougly analyzed, engineered, and tested prior to any field testing. Failure to do so could result in serious problems.

I PURPOSE AND METHODOLOGY OF THE STUDY

The thermal spallation drilling system designed and evaluated in the body of the main report used an umbilical or hose as a means to transport air, oxygen, fuel, and water from the surface to the down hole burner system. This umbilical also provided a mechanical link between the two systems. When the concept was technically evaluated, it was noted that the use of an umbilical greater than approximately 7000 feet in length would present engineering design problems and field operational problems that would be extremely difficult, if not impossible, to overcome. However, the economic evaluation indicated that the drilling economics of a flame jet system were far superior to those of a conventional rotary rig when drilling holes in granite. Thus, it became apparent that a different means of communicating with and mechanically linking the down hole burner to the surface equipment was needed. A system that may overcome these difficulties has been envisioned by Los Alamos National Laboratories (LANL). It is the purpose of this supplemental report to both technically and economically evaluate this new system.

To achieve the above stated purpose, a thermal spallation rig shall be conceptually designed using both the LANL concept and applicable information from the original study wherever possible. The design and economic characteristics of this new design shall then be incorporated into the previously developed comparative drilling economic model to determine the economic advantage of the system. An analysis of both the technical and economic results will then be made.

II THERMAL SPALLATION DRILLING RIG DESIGN

A. Design Overview

The design philosophy used for this rig will be similar to that of the flame jet rig designed in the main report. In that design, the drilling rig could be used either as a conventional rotary rig or as a flame jet rig. Conversion time was kept as short as possible. The design also assumed that all components were commercially available and thus component cost did not include development and/or field test cost. This economic assumption is necessary to perform an equitable evaluation between the conventional rig and the flame jet rig.

B. Rig Specifications

The flame jet system to be designed must be capable of drilling the generic well models established in the main report. For purposes of this report, however, only generic well model No. 1 will be used. This model is noted in Figure 1. It is further assumed that this well is vertical and does not deviate out.

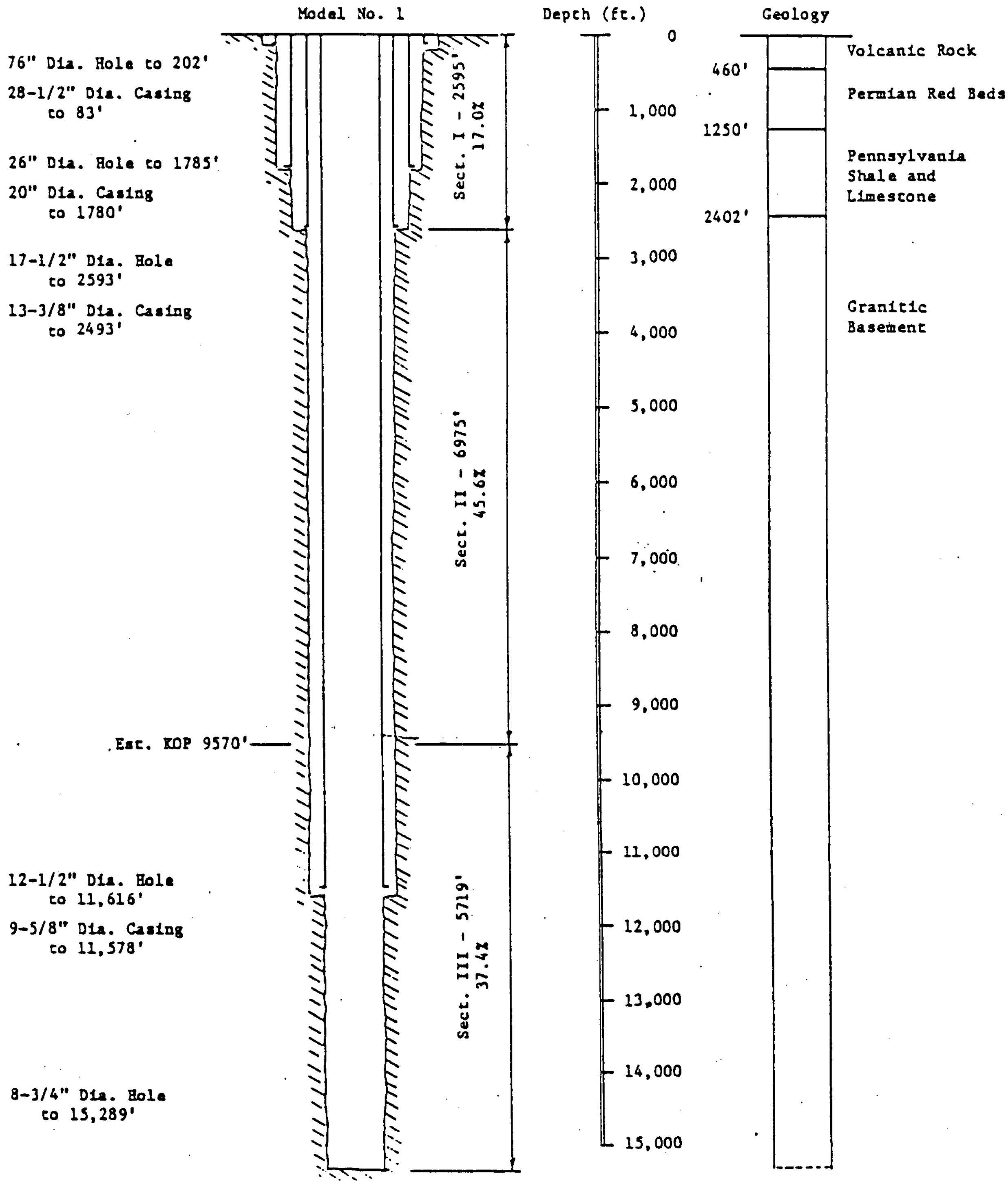
The spallation operation will be accomplished by using and air/fuel system. The volume and characteristics of the fluids used will be as follows:

1.) Fuel

Propane gas C_3H_8 shall be used as the fuel. Propane gas and air ignite as follows:

$$C_3H_8 + 5O_2 + 18.88N_2 = 4H_2O + 3CO_2 + 18.88N_2$$

• Wt/lb Fuel: 1 + 3.63 + 12.0 = 1.63 + 3.0 + 12.0



GENERIC WELL MODEL NO. 1

Figure 1

- Weight of Fuel:

$$\text{s. g. of } C_3H_8 = .582$$

$$1 \text{ gal } C_3H_8 = (.582)(8.357) = 4.86 \text{ lbs}$$

- Using Lynde experimental mixture of 72 gph of propane:

$$72 \text{ gph} = 1.2 \text{ gpm}$$

$$1.2 \text{ gpm} = (1.2)(36.39) = \underline{43.67 \text{ cfm propane}}$$

2.) Air

From the above equations, 15.63 lbs of air will be required for each pound of fuel.

$$\text{Lbs of air/min required} = (1.2)(4.86)(15.63) = 91.15$$

$$91.15 \text{ lbs of air/min} = (91.15)(13.10) = \underline{1194.12 \text{ cfm air}}$$

3.) Water

As noted in the main report, water is used for cooling the burner, cooling the well walls, quenching rock particles, and assisting in the lift process. Water will be consumed at the rate of <u>20 gpm</u> with a surface pump pressure of 200 psi.

4.) Boost Air

It was noted in the main report that approximately 2850 cfm of boost air was required at certain times to assist in removal of cuttings from the hole. This volume shall also be used in this report even though the true value required for drilling with propane may be slightly different.

C. Rig Design

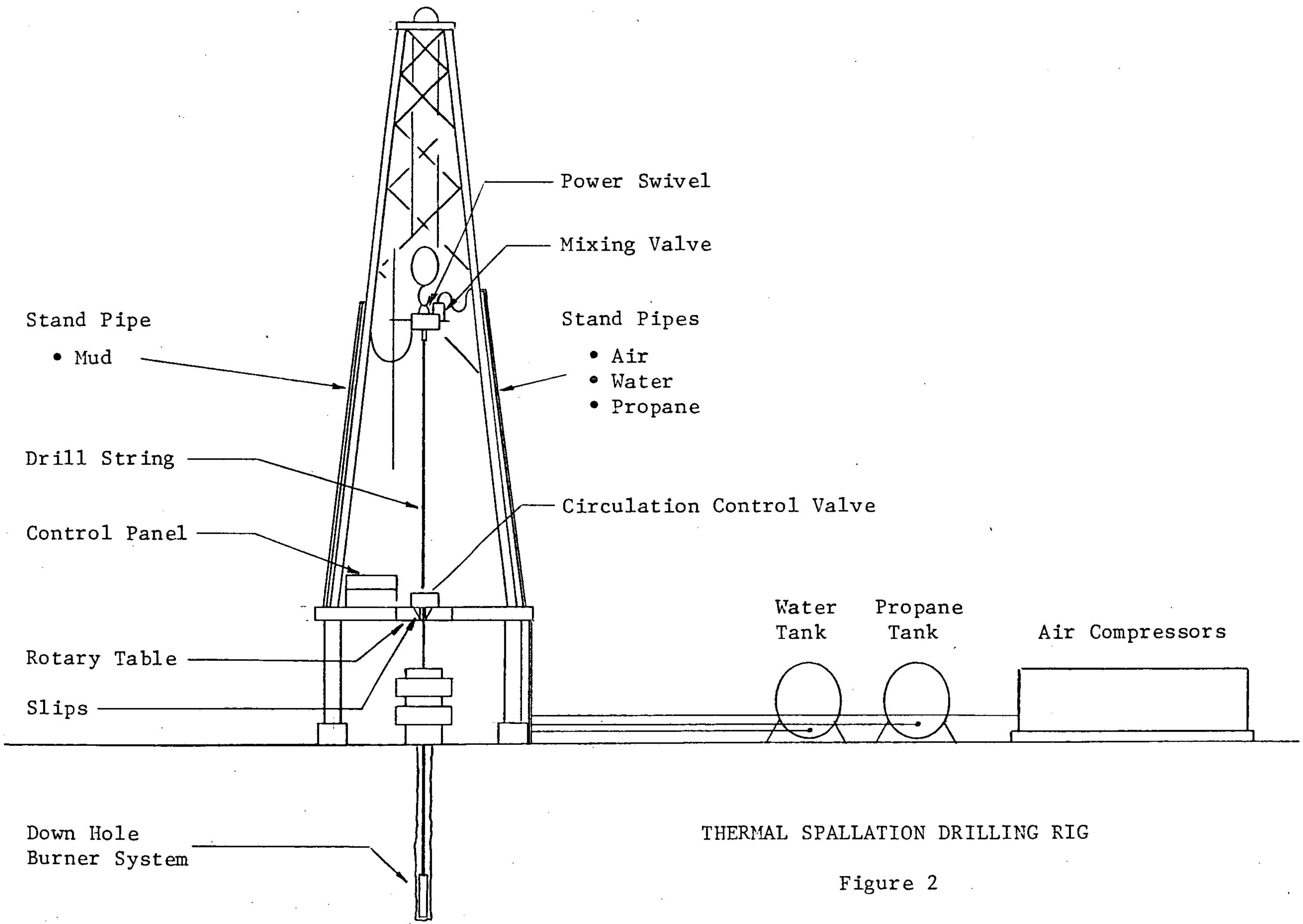
The envisioned rig design integrates a flame jet drilling system into a conventional rotary drilling rig as noted in Figure 2. This concept consists of the four main systems indicated in Figure 3. The four main systems are:

- Surface System
- Down Hole Transport System
- Down Hole Burner System
- Control System

These are essentially the four main systems used in the original design, except they are modified to eliminate many of the identified problems.

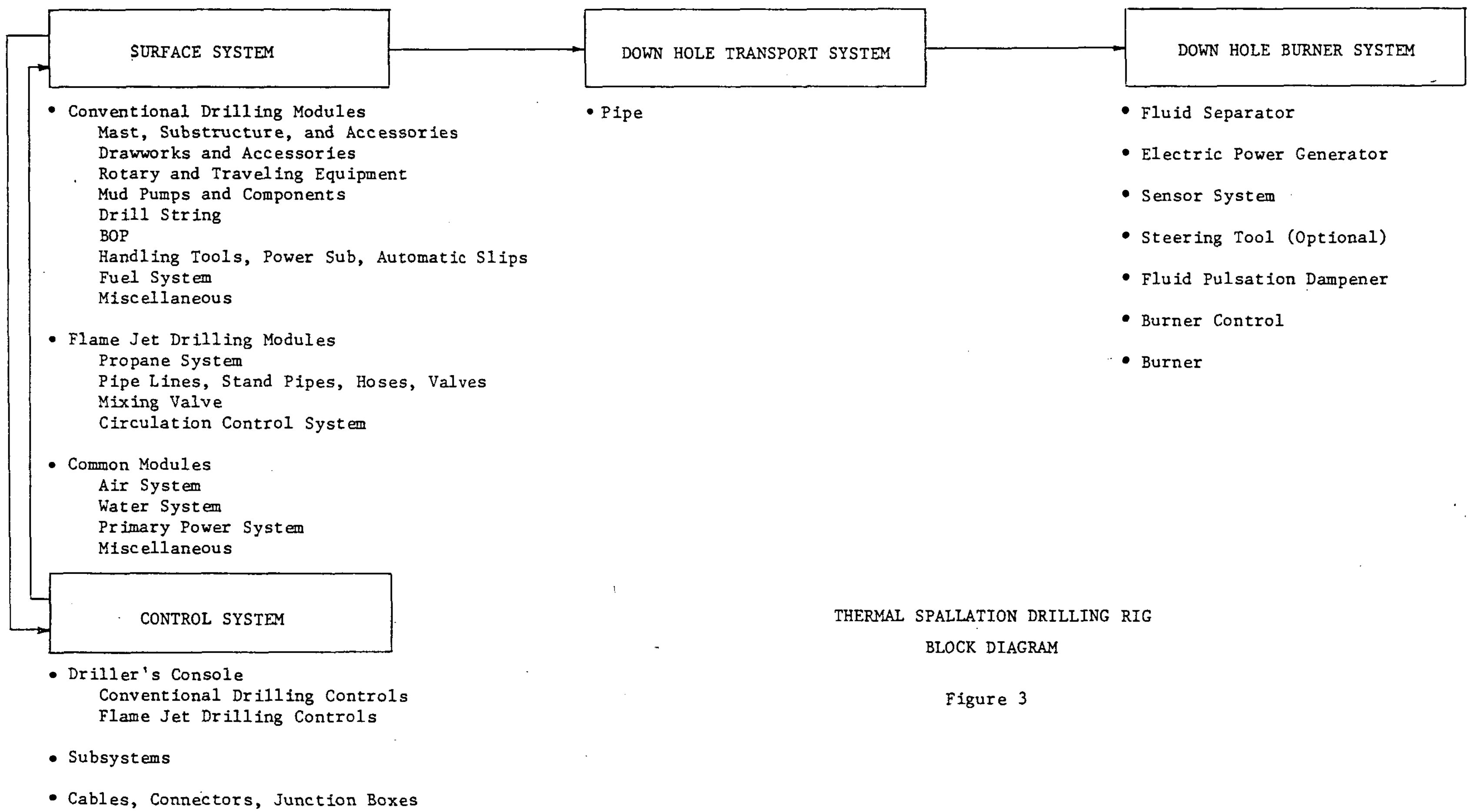
In the following sections of this report, each system and its components shall be reviewed and/or conceptually designed to that degree which will allow one to determine its capabilities and its design constraints. Even though this system is a modification of the original design, it is necessary to provide this amount of detail work to assure the feasibility of the system so that if one desires to further pursue this system, a sound conceptual design base will have been established.

It is necessary to emphasize that all cost estimates assume that the components are made in quantity and that engineering costs are not included. In this way an estimated cost can be developed that will be on a fair and equitable basis with the cost of standard equipment obtained from vendors. The cost evaluation shall further assume that the component can be made in a reasonable manner and that its design will provide an efficient and reliable system. This last assumption is a major factor that must be fully understood as one progresses in analyzing this report.



THERMAL SPALLATION DRILLING RIG

Figure 2



THERMAL SPALLATION DRILLING RIG
BLOCK DIAGRAM

Figure 3

1. Surface System

Conventional Drilling Modules

Most of the equipment required for conventional rotary drilling is included in this group. In general, they are standard oil field components and require no modification for use with this system. Most of these components are similar to those used in the original system.

- Mast, Substructure, and Accessories

  Mast, Substructure, BOP Hoist, Catwalks, Pipe Racks, Standpipe and Manifold, Wireline Guide Assembly, Hanging Assembly, Deadline Stabilizer

  Estimated Cost: $800,000

- Drawworks and Accessories

  Drawworks, Breaking System, Sand Reel Assembly, Crown Safety System, Catline Grip Assembly, Rotary Table Emergency Drive

  Estimated Cost: $415,000

- Rotary and Traveling Equipment

  Hook, Traveling Block, Swivel, Sandline, Wire Rope and Reel, Kelly, Kelly Bushing, Kelly Wiper, Kelly Valves, Rotary Table, Rotary Drive, Master Bushing, Rotary Hose

  Estimated Cost: $260,000

- Mud Pumps and Components

  Mud Pumps, Pulsation Dampeners, Vibrator Hose, Mud Tanks, Shale Shakers, Desanders, Desilters, Mixing Equipment, Suction Hose

  Estimated Cost: $840,000

- Drill String

  Drill Pipe (16,000 ft.), Collars, Subs, Pup Joints

  Estimated Cost: $770,000

- BOP

  Blowout Preventers, Choke and Kill Manifold, Controls, Manifold System, Hydraulic System

  Estimated Cost: $325,000

- Handling Tools

  Elevators, Spinning Wrench, Tongs, Power Sub, Automatic Slips, Safety Clamps

  Estimated Cost: $92,000

- Fuel System

  Fuel Tanks, Pumps

  Estimated Cost: $13,000

- Miscellaneous

  Dog House, Mud Storage, Hoist Lines

  Estimated Cost: $50,000

Flame Jet Drilling Modules

This group of modules relates directly to the flame jet drilling operation.

- Propane System

In the main study, the computer program for flame jet drilling of the first generic well model estimated that 182 hours of flame jet operation was required to drill the well. Using this time factor and the previously specified fuel use rate, it can be estimated that 13,104 gallons of propane fuel will be required to drill the well.

Total Fuel Consumption = (182)(72) = 13,104 gal.

Liquid propane is normally stored in horizontal, skid mounted tanks that are leased and serviced by a supplier of the fuel. This cost includes an unloading system, piping, safety equipment, etc. This type of equipment will be required at the drilling site.

Estimated Cost:

Fuel Storage, 18,000 gal. System, Lease Cost	- $17,000
Fuel Cost, Liquid Propane	- $.62 gal.

* Pipe Lines, Stand Pipes, Hoses, Valves

A series of pipes, hoses, valves, etc., are required to transport the compressed air, the water, and the fuel from their compressors and/or storage tanks to the mixing valve located on the traveling power sub. The three fluids will travel in separate pipes to the mixing valve so that they can be combined in the proper proportions at that point. If these fluids were mixed earlier, they may tend to separate because of the vertical travel required in the stand pipe. Also, the water may tend to collect at the bottom of the loop in the hanging hose bundle and thereby block passage of the other fluids.

The piping system will consist of three main sections. The first section will transport the fluids from the compressors and tanks to the rig substructure. This section will be made up from hoses so that the placement of the compressors and tanks can be somewhat flexible. The second section will transport the fluids vertically up the side of the rig substructure and the mast. This section shall consist of hard pipe permanently bolted to the various structural elements. The third section will transport the fluids from the top of the vertical pipe to the traveling power sub. This section shall consist of a bundle of three hoses and a steel safety cable. The hoses shall be clamped at set intervals to the safety cable so that they will not fall free in the event of rupture. All components in the three sections stated above shall be designed to withstand the necessary system pressures. No design problems are anticipated.

Estimated Cost: $20,000

• Mixing Valve

This valve is located on the traveling power sub. Its main function is to combine the air, the water, and the fuel in the required proportions prior to entering the power sub. A remote controlled, electrical shut-off valve shall be placed between the mixing valve and the power sub so that the fluids can be shut off whenever the power sub is disengaged from the down hole transportation system, or in the event of an emergency. No engineering problems are anticipated in the design of this equipment.

Estimated Cost:

Mixing Valve, Electric Shut-off Valve,
Electric Cable - $5,000

- Circulation Control System

Because of the pressure required in the down hole transportation system, and the time required to build up this pressure, a device is required to maintain this pressure whenever the down hole transportation system is disengaged from the traveling power sub. Such conditions can occur when adding a new section of pipe, during certain repair operations, etc. A device that may solve this problem is noted in Figure 4. This device is capable of diverting the fluid pressure and flow from the bottom of the stand pipe to a shut-off valve directly above the down hole transportation system. The shut-off valve allows the addition of pipe without the loss of down hole pressure. No engineering problems are envisioned in the design of this equipment.

The problem of adding new sections of pipe to the down hole transportation system must be thoroughly evaluated because of the potential of creating an explosion due to the unignited fuel that will accumulate in the hole. This will be discussed in detail in a later section of this report.

Estimated Cost:

Circulation Control Valve, Electric Flow Control Valve, Piping, Electric Cable - $3,000

United States Patent [19]

Stallings

[11] 4,315,553

[45] Feb. 16, 1982

[54] CONTINUOUS CIRCULATION APPARATUS FOR AIR DRILLING WELL BORE OPERATIONS

[76] Inventor: Jimmie L. Stallings, 4560 Pinto La., Claremore, Okla. 74017

[21] Appl. No.: 180,655

[22] Filed: Aug. 25, 1980

[51] Int. Cl.[3] E21B 19/00; E21B 21/10; E21B 33/02

[52] U.S. Cl. 175/207; 175/71; 175/212; 175/218

[58] Field of Search 175/207, 209, 210, 212, 175/214, 218, 65, 71; 166/77, 77.5, 84, 95

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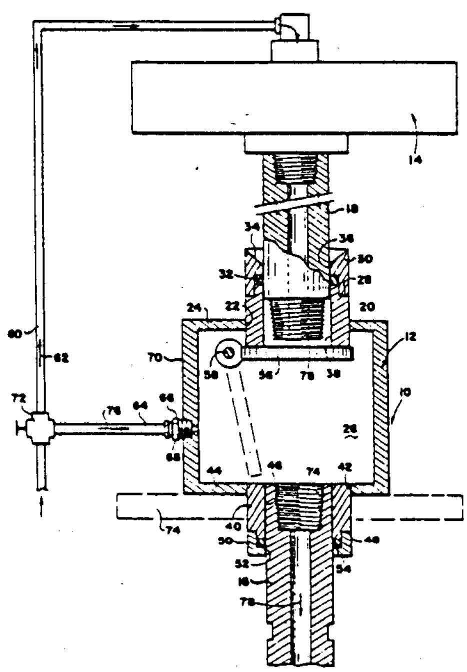
Primary Examiner—Stephen J. Novosad
Attorney, Agent, or Firm—Head & Johnson

[57] ABSTRACT

An apparatus for maintaining a continuous supply of air pressure downhole during a well bore drilling operation, even during the addition of a pipe section to the drill string, and comprising a housing installed at the surface of the well at the position of the drilling equipment wherein the upper end of the drill string is separated from the drive mechanism in order that a new piece of drill pipe may be added to the drill string, a flapper or closure member pivotally secured within the housing normally held in an open position by the outer periphery of the drill string and spring urged in a direction toward the open end of the sleeve through which the drive mechanism passes when the drive mechanism has been backed off or removed for the addition of a section of pipe to the drill string, and a by-pass line in communication with the interior of the housing for directing air pressure from the air supply to the housing when the flapper member is in the closed position whereby the air pressure may be circulated downwardly through the drill string for maintaining the air circulation downhole during the entire drilling operation.

6 Claims, 1 Drawing Figure



CIRCULATION CONTROL VALVE

Figure 4

Common Modules

- Air System

The air system shall be similar to the original flame jet design as noted in Figure 5. System pressures may, however, vary from those noted, based upon operational requirements. Further, the 800 SCFM compressor will have to be upgraded to a higher pressure level so that it can be hooked directly into the 500 psi line.

The costs stated in Figure 5 relate to the purchase of the equipment noted. For purposes of this report, equipment costs shall be evaluated two ways, the first being the purchase cost and the second being a rental or lease cost. The advantages of leasing or renting lie in paying for the equipment only when it is needed, and the equipment is normally in good condition. Rotary drilling air is costed separately and will be included in the original cost of the rig.

Estimated Cost:

- Equipment Purchase

Rotary Drilling Air	- $ 6,850
Flame Jet Drilling Air	- $739,000

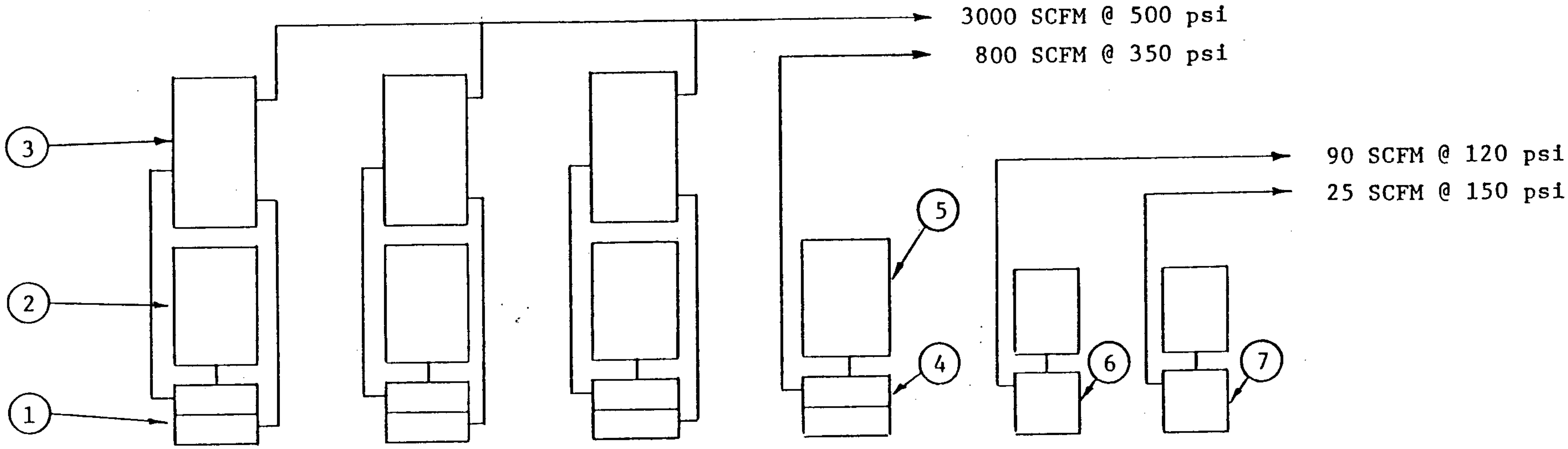
- Equipment Rental

Flame Jet Drilling Air	
1-C25 Centac 2500 cfm, 125 psi	- $600/day
1-IR Trailer 1150 cfm, 125 psi	- $400/day
1-IR Air Pressure Booster 1500 psi	- $800/day

- Equipment Maintenance - $1000/mo.

It should be noted that the above stated rental equipment is all diesel powered. The rental rate will decrease if electric motor powered equipment can be found. Electric motors can be powered by the rig primary power system.

AIR SYSTEM



Item	Description	Quantity	Unit Cost $	Total Cost $
	• Flame Jet Drilling Air:			
1	Compressor, Ariel Corp., Model J/G-4	3	165,000*	495,000
2	Motor, G. E., 320 KW, 1200 RPM	3	32,000	96,000
3	Cooler, Air-X-Changer, Type H	3	-	-
4	Compressor	1	135,000	135,000
5	Motor	1	13,000	13,000
	• Rotary Drilling Air:			
6	Compressor & Motor, Quincy, DF390-120	1	3,900	3,900
7	Compressor & Motor, Quincy, DF325-60	1	2,950	2,950

* Includes Cost of Cooler, Item 3

Figure 5

With regard to diesel fuel consumption, a rough estimate is as follows:

C25 Centac Compressor	800 gals./24 hr. day
IR Trailer Compressor	400 gals./24 hr. day
IR Air Pressure Booster	800 gals./24 hr. day

It should also be noted that a cost of $200/24 hr. day has been added to the C25 Centac day rate. This covers the cost of the 40 gpm water cooling system required to properly operate the Centac.

• Water System

The water system shall be similar to that used in the original flame jet design.

Estimated Cost: $37,000

• Primary Power System

The primary power system shall be similar to that used in the original flame jet design. The power distribution system shall be different in that this new flame jet system does not require the powered surface equipment of the original design. Thus, a much simpler distribution system will be used.

Estimated Cost: $1,200,000

• Miscellaneous

The miscellaneous components consist of a series of tools and components used with either drilling system. They are standard oil field components and will need little or no modification.

Estimated Cost:

Fire Fighting Equipment	-	$ 20,000
Hand Tools	-	8,000
Tool House	-	20,000
Wire Line System	-	12,000
Welding Tools	-	5,000
Rig Lights	-	20,000
Other	-	30,000
Total	-	$115,000

2. Down Hole Transport System

- Pipe

The purpose of the down hole transport system is to transfer the working fluids for flame jet drilling from the surface system to the down hole burner system, and to provide a physical link between these two elements. The system used in this design is totally different from that of the original design. In this design, the air, fuel, and water are mixed together by the mixing valve on the traveling power sub and then transported down hole to the burner. The transport system used is the conventional drill pipe used by the drilling rig. Thus, no additional surface equipment or cost is required.

In the event problems are encountered in the mixing and separation of the three fluids, Con-Cor^{R} pipe, Figure 6, manufactured by the Walker-Neer Co., Wichita Falls, Texas, can be used. This pipe consists of a modified drill pipe and a concentrically oriented inner tube that is field removable for easy servicing. The outer pipes are connected with special thread forming metal to metal seals. The inner tubes telescope together and seal by means of elastomer-to-metal seals. Thus, the pipe annulus is sealed off from the inner tube passage. If this pipe is used, the fuel can be transported separately in the inner tube, and the air/water mixture transported down the annulus.

Because of the dual pipe system, maintaining system pressure and keeping the fluids separated during the addition of a new joint of pipe to the drill string will present some problems. Thus, the circulation control valve, Figure 4, will have to be redesigned.

If no problems are encountered in the mixing and separation of the three fluids, consideration should be given to using a modified version of the Case While Drilling (CWD) system. In this concept, the casing acts as the drill string, and the down hole burner is tripped in and out on a wire line. The advantage of this system is the reduction of trip time. It should be noted, however, that trip time is not an important factor when flame jet drilling because of the potentially high, continuous time of making hole with the flame jet.

Considering the above concepts, there does not appear to be any serious engineering problem in the design of the transport system. Because use of drill pipe is the simplest and least expensive solution, it shall be used first in this study.

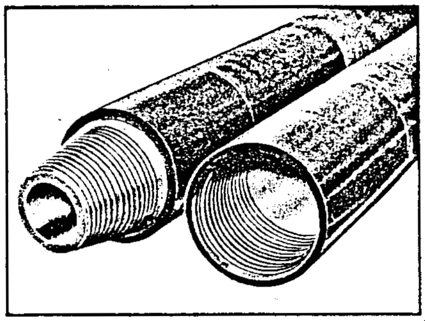
No additional costs are required when using conventional drill pipe. The use of Con-Cor® pipe does, however, add cost because a new drill string is required. This string will cost approximately $1,500,000 for 15,000 feet of pipe and will probably have to be replaced in approximately 1-1/2 years. Since it is used only part of the time, an additional cost of $250/hr. must be added to the flame jet operating rate.

Estimated Cost:

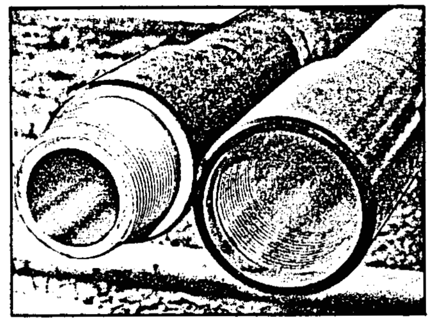
Conventional Drill Pipe	- Cost included with conventional rig equipment
Con-Cor® Drill Pipe	- $250/hr.

Conventional Drill Pipe

• Flush OD Tool Joints, Plain End Pipe: 3½" - 13⅜" O.D.

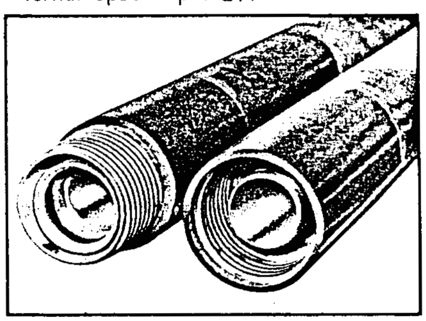


• External Tool Joints, Plain End or Oil Country External Upset Pipe: 2⅞" - 13⅜" O.D.

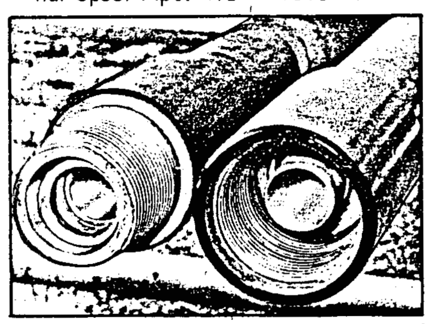


CON-COR® Drill Pipe

• Flush O.D. Tool Joints, Plain End or Internal Upset Pipe: 2¾" - 5½" O.D.



• External Tool Joints, Plain End or External Upset Pipe: 4½" - 13⅜" O.D.



CON-COR[R] DRILL PIPE

Figure 6

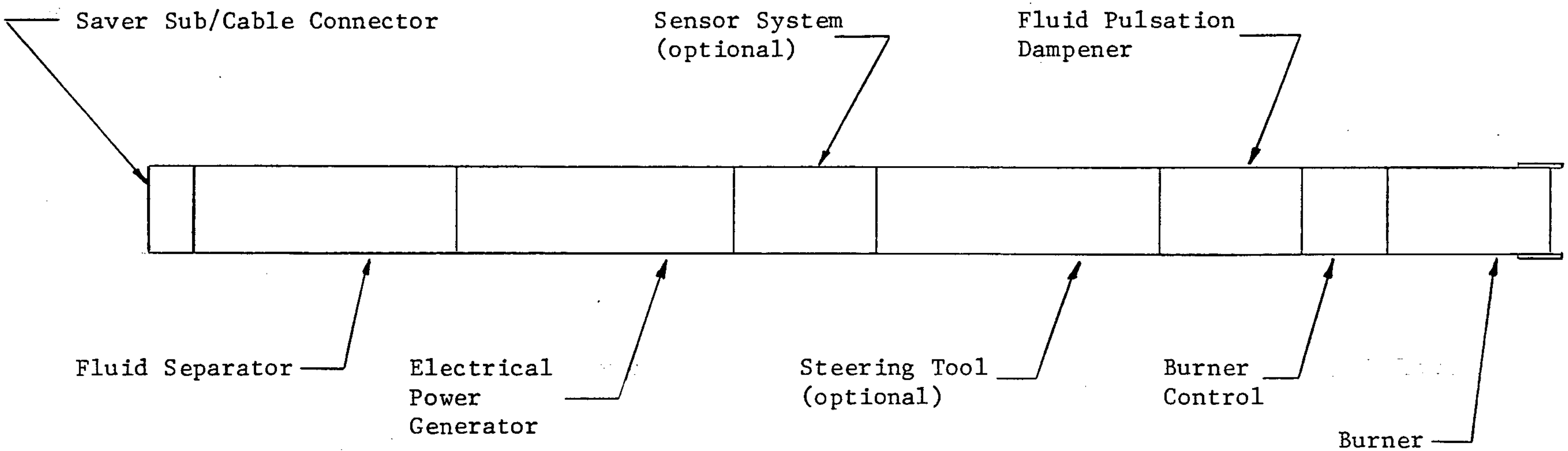
Ref: Walker-Neer Co., Wichita Falls, Texas

3. Down Hole Burner System

The down hole burner system consists of the flame jet burner and the necessary controls and guidance equipment required for the burner to operate properly. This combination of equipment will be assembled in a manner similar to that of Figure 7. The main components of the assembly are:

- Fluid Separator
- Electric Power Generator
- Sensor System (optional)
- Steering Tool (optional)
- Fluid Pulsation Dampener
- Burner Control
- Burner

These components are all mechanically interlocked. A mechanical saver sub or cable connector is provided at the aft end of the assembly to allow connection of the total assembly to the drill pipe or to a wire line. The choice of connector will be based upon the final configuration developed.



DOWN HOLE BURNER SYSTEM

Figure 7

• Fluid Separator

As previously stated, the method of fluid transportation used from the surface to the down hole burner is to mix the air, the water, and the fuel together at the surface and transport it to the burner system via the drill string. As soon as this mixture reaches the burner system, it enters a fluid separator. This device is a mechanical moisture separator similar to that noted in Figure 8. The device works by means of centrifugal separation at either high or low velocities.

As noted in Figure 9-A, the vapor-laden fluid enters the separator and approaches the helicoid tuyere. The tuyere forces a gradual change of fluid direction. The pitch angle of the tuyere blades is designed so that the gas will contact the full surface of the blades, which acts as an agglomerator. The gas passing through the tuyere is directed inward by the angular edge of the blade, while the liquid particles are forced toward the wall by centrifugal action. The liquid then flows down the wall surface to the drain, while the inward directed gas is forced toward the outlet tube. The gas enters the tube and then leaves the separator.

Under proper conditions, this separator will operate as stated above. However, the separator design must be fully evaluated with regard to the flow requirements of the flame jet system. Questions of immediate concern are:

- Can the separator be designed to fit the diametric space requirements of the burner system, and yet efficiently and effectively handle the large volume of fluids required for flame jet operation?

- Will the efficiency of the tuyere be such that the air/propane gas mixture will be sufficiently "dry" to support ignition?

- What is the effect of the centrifugal action on the air/propane gas ratio?

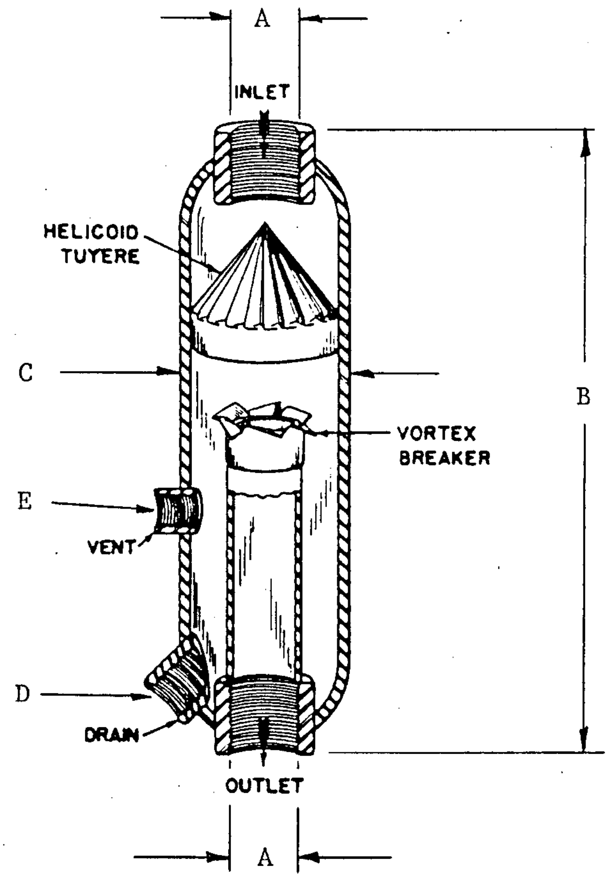
- If the water in the fluid mix agglomerates on the drill pipe wall and then flows down the wall, will this fluid block the inlet to the tuyere and/or disrupt its proper operation?

Although the separator can purge water from the fluid mix, it must be understood that the volume of air in the fluid mix is used for both boost air and combustion air. Thus, the air/propane gas mixture must also be separated into its two basic components. This is necessary to assure that the correct air/propane ratio is obtained for combustion purposes. Further, one does not want to use the propane gas as a particle lift fluid.

Considering the above statements and questions, it may be desirable to use the Con-Cor^{R} pipe system previously described. If that system was used, the propane gas could be transported separately in the inner tube and the air/water mix in the annular area. In this way the propane gas would remain dry and the air could be divided into its two primary functions after it leaves the tuyere.

Based on the above, it would appear that the fluids can be transported and separated properly. However, this area should be thoroughly investigated prior to any major development program.

Estimated Cost: $7,500

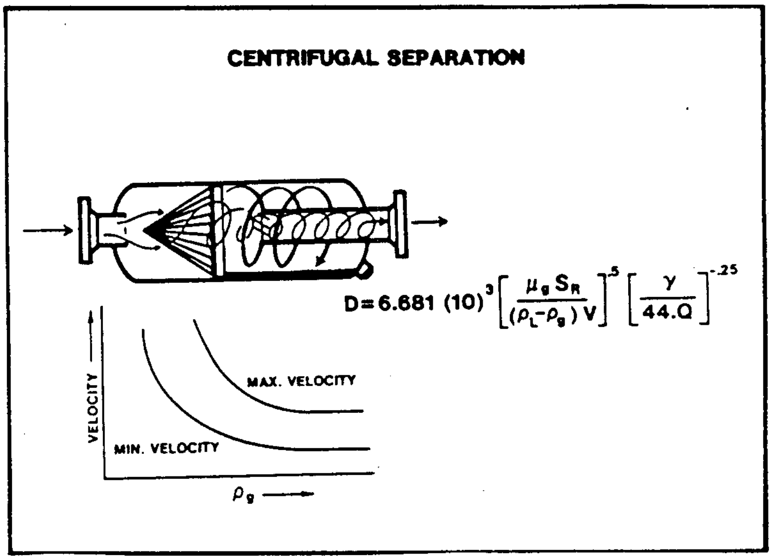


A UNIT SIZE	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
B LENGTH	$8\frac{7}{8}$	$8\frac{7}{8}$	$8\frac{7}{8}$	15	15	17	18
C DIAMETER	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{9}{16}$
D DRAIN SIZE	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$
E VENT SIZE	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
WEIGHT - LBS.	4	4	4	11	13	17	28

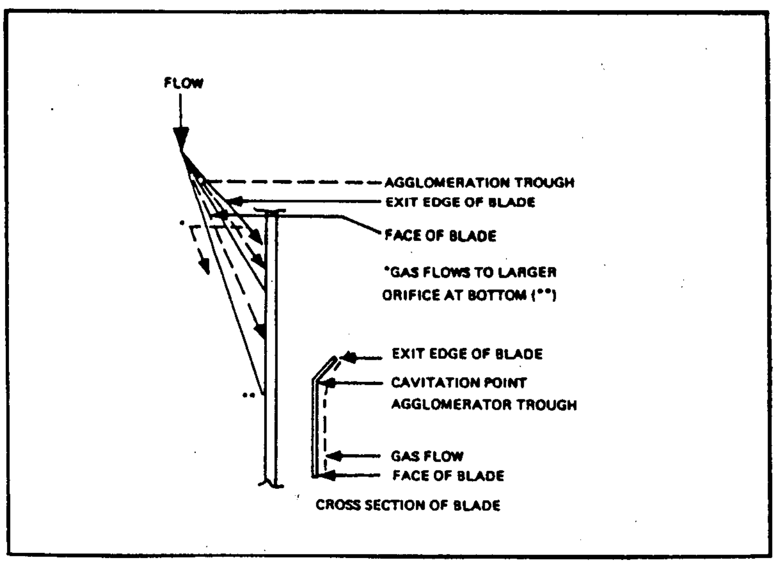
MECHANICAL MOISTURE SEPARATOR

Figure 8

Ref: Burgess Manning, Inc., Dallas, Texas



(A)



(B)

OPERATIONAL CHARACTERISTICS OF
MECHANICAL MOISTURE SEPARATOR

Figure 9

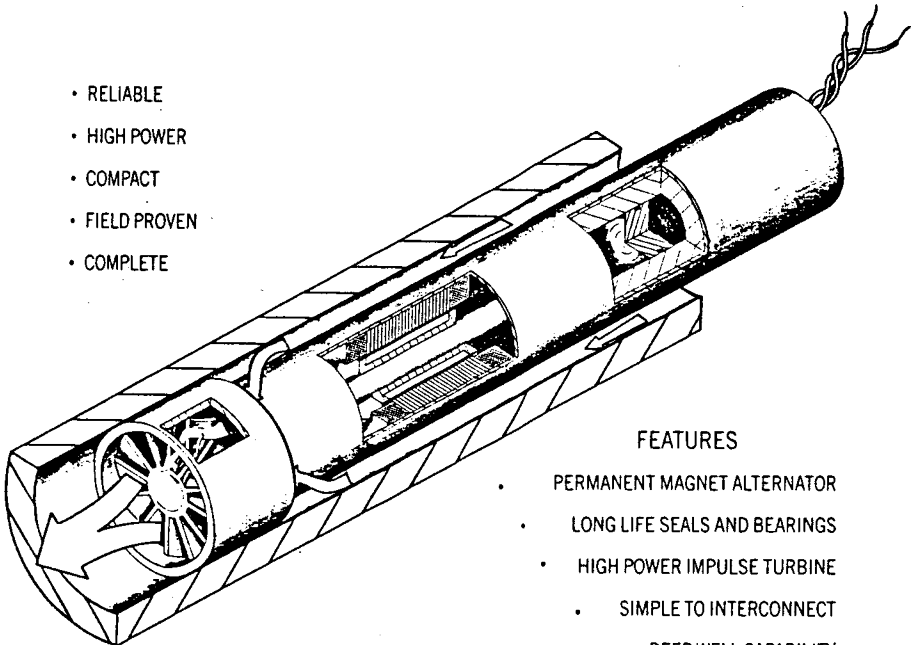
- Electric Power Generator

The purpose of this device is to provide power for a spark ignition system required to ignite the air/propane mixture. Previous evaluation of drilling procedures states that there are instances when the burner must be ignited or re-ignited down hole. Thus, a down hole power source is required.

Down hole power generators, Figure 10, have been built and used successfully in the field. It therefore appears that an effective unit can be built for this system. However, redesign will be required to obtain the proper electrical characteristics and the proper routing of the air, the water, and the propane gas through this device. No serious engineering problems are envisioned.

Estimated Cost: $20,000

- RELIABLE
- HIGH POWER
- COMPACT
- FIELD PROVEN
- COMPLETE



FEATURES

- PERMANENT MAGNET ALTERNATOR
- LONG LIFE SEALS AND BEARINGS
- HIGH POWER IMPULSE TURBINE
- SIMPLE TO INTERCONNECT
- DEEP WELL CAPABILITY
- LOW PRESSURE DROP
- EASY TO MAINTAIN

DESCRIPTION

The MEI model 3500 and model 4000 downhole turbine generators are complete AC power systems for drilling, MWD and production applications. Both models include mechanical power train, seals, oil enclosure, alternator, radial and thrust bearing systems, pressure compensator and means to mount and connect the units into downhole hardware and instrumentation.

The compact and reliable brushless, permanent magnet alternator operates in an oil filled, pressure balanced enclosure. The MEI patented impulse turbine power train delivers surplus driving power at predictable speeds. Yet, it can pass most lost circulation materials without plugging. The wide range of flow rates accommodated by the system can be extended significantly by interchanging blade systems or flow bypass plates. The units operate in either a normal (blade down) or inverted (blade up) orientation.

Units are designed for long life, and they are easy and economic to maintain. Customized engineering service is provided to match units to each user's application.

	MODEL 3500	MODEL 4000
ALTERNATOR		
Type	Three-phase, Permanent Magnet	
Number of Poles	4	8
Configuration	Wye	Wye
Max. Continuous Power @ 70°F	500 Watts	1000 Watts
Maximum Current	12 Amps	10 Amps
DC No-load Voltage @ 2,500 rpm	27 Volts	57 Volts
DC No-load Voltage @ 5,000 rpm	54 Volts	115 Volts
DC Voltage @ 10A, 2,500 rpm	17 Volts	51 Volts
DC Voltage @ 10A, 5,000 rpm	44 Volts	107 Volts
AC No-load Voltage @ 5,000 rpm	113 Volts	145 Volts
Max. Winding Temperature	392°F (200°C)	392° (200°C)
MECHANICAL		
Turbine Shroud Diameter	4.250 in.	4.750 in.
Body Diameter	3.625 in.	3.750 in.
Turbine Speed @500 gpm	5000 rpm	5000 RPM
Pressure Drop Across Tool	30 psi @ 350 GPM	
NORMAL OPERATING CONDITIONS		
Flow Rate	250 - 500 GPM	
Temperature	70 - 300°F	

OPTIONS

- External Housing
- Fluid Bypass Plates
- Customized Voltage/Power
- Low Flow/High Speed Blades
- High Flow Blades (To 1200 GPM)

DOWN HOLE ELECTRIC POWER GENERATING SYSTEM

Figure 10

Ref: Maurer Engineering, Inc., Houston, Texas

• Sensor System (optional)

The sensor system is an optional system that is necessary if direction control is required. It obtains and transmits position and geological data to the surface. This data includes azimuth, inclination, tool face orientation, etc. An example of this type of equipment is illustrated in Figure 11-A. In that illustration, the steering tool, the orientation sub, and the electrical connection make up the sensor system.

This type of equipment is normally rented or leased from a service company.

Estimated Cost:

Rental Rate	$2,000/day

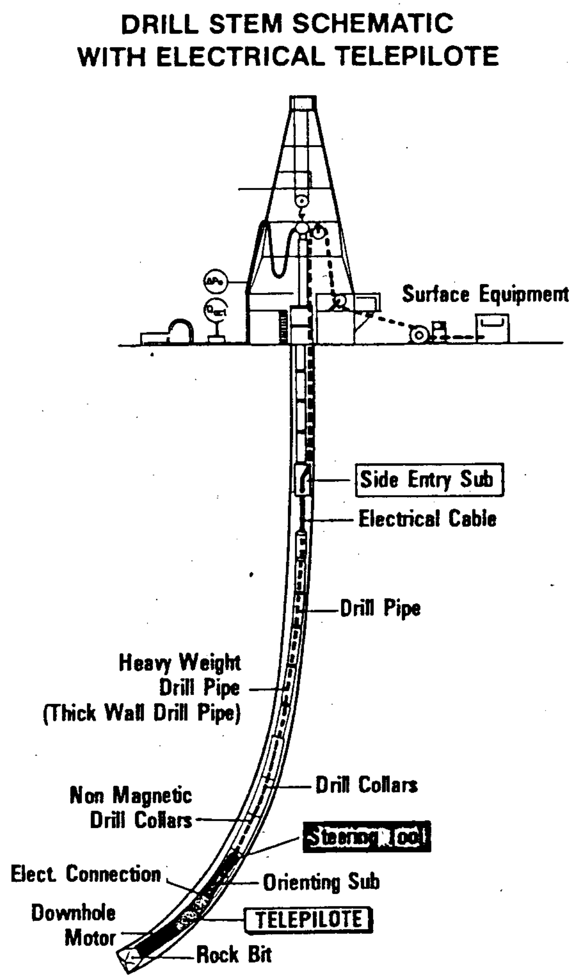
• Steering Tool (optional)

The steering tool is an optional system that is necessary if directional control is required. A number of these devices are commercially available. The only electrically controlled device available is noted in Figure 11-B. It must be used in conjunction with the sensor system previously described.

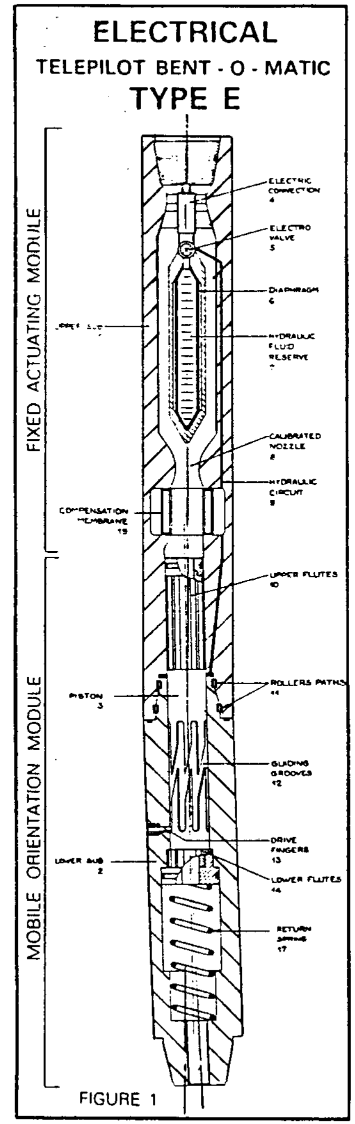
This type of equipment is normally rented or leased from a service company.

Estimated Cost:

Rental Rate	$2,000/day



(A)



(B)

DOWN HOLE DIRECTIONAL CONTROL SYSTEM

Figure 11

Ref: SMF International, Paris, France

- Fluid Pulsation Dampener

Fluid pulsation dampeners are required to eliminate or reduce the non-steady-state flow of the air and propane prior to their entering the burner control system. The non-steady-state condition is created by the pulsation effects of the fluid pumps and compressors, plus the effects of temperature changes on the fluids as they traverse the length of the drill string. Elimination of this condition is required so that an even flowing, properly proportioned air/fuel ratio can be obtained. The design of this equipment is fairly standard. Thus, no engineering problems are anticipated.

Estimated Cost: $15,000

* Burner Control

The burner control is a mechanism that meters the air and fuel to the proper ratio prior to entrance into the combustion chamber. It also incorporates the ignition control and system. No engineering problems are anticipated in the design of this system.

Estimated Cost: $3,000

* Burner

The burner produces the high temperature, high velocity flame jet by ignition of the air/propane mixture. Burners can be obtained without difficulty. No engineering problems are envisioned.

Estimated Cost: $3,000

4. Control System

The control system incorporates the controls necessary to operate both the conventional rotary rig and the flame jet rig. The system is similar in design to that of the control system used in the original design, except that it is simpler because fewer components are involved. No engineering problems are anticipated in the design of this equipment.

Estimated Cost:

• Drillers Console		
Conventional Drilling Controls	-	$ 68,700
Flame Jet Controls	-	60,000
• Subsystems	-	10,000
• Cables, Connectors, Junction Boxes	-	15,000
Total	-	$153,700

D. Rig Cost Summary

An estimated cost has been made for each of the various systems and components of the thermal spallation drilling rig. As previously stated, these costs are based, when possible, upon vendor information and engineering design judgement. Thus, error in cost estimation is very possible.

In general, this error will be limited to the flame jet drilling equipment. Further, this error will probably be manifested in under-estimating component cost. Therefore, it can be stated that in all probability the cost of the conventional drilling system is fairly accurate, while the cost of the flame jet rig may be too low. An error factor of as much as 10% to 15% may be involved in the flame jet rig cost.

A tabulation of all costs involved is stated in Table 1. It should be noted that no cost is stated for the propane system and the flame jet drilling air. Equipment for both of these items will be leased. Propane gas will be purchased as needed. Further, no cost is stated for the transportation pipe because the drill pipe, which was previously costed with the drilling equipment, will be used. The optional sensor system and steering tool are also lease or rental type items and can be obtained when needed.

THERMAL SPALLATION DRILLING RIG

COST SUMMARY

Table 1

A. System/Component Cost:			
1. Surface System			
• Conventional Drilling Modules			
Mast, Substructure and Accessories	$ 800,000		
Drawworks and Accessories	415,000		
Rotary and Traveling Equipment	260,000		
Mud Pumps and Components	840,000		
Drill String	770,000		
BOP	325,000		
Handling Tools, Power Sub, Automatic Slips	92,000		
Fuel System	13,000		
Miscellaneous	50,000	$3,565,000	
• Flame Jet Drilling Modules			
Propane System	--		
Pipe Lines, Stand Pipes, Hoses, Valves	20,000		
Mixing Valve	5,000		
Circulation Control System	3,000	28,000	
• Common Modules			
Air System			
Rotary Drilling Air	6,850		
Flame Jet Drilling Air	--		
Water System	37,000		
Primary Power System	1,200,000		
Miscellaneous	115,000	1,358,850	
2. Down Hole Transportation System			
• Pipe	--	--	
3. Down Hole Burner System			
• Separator	7,500		
• Generator	20,000		
• Sensor System (optional)	--		
• Steering Tool (optional)	--		
• Pulsation Dampener	15,000		
• Burner Control	3,000		
• Burner	3,000	48,500	
4. Control Console			
• Driller's Console			
Conventional Drilling Controls	68,700		
Flame Jet Drilling Controls	60,000		
• Subsystems	10,000		
• Cables, Connectors, Junction Boxes	15,000	153,700	
5. System Rig Up, Test, Rig Down		450,000	
Total System Component Cost		$5,604,050	
B. Specific Drilling System Cost:			
1. Conventional Rotary Drilling System		$5,442,550	
2. Flame Jet Drilling System		161,500	
Total System Cost		$5,604,050	

III OPERATING CHARACTERISTICS

The drilling rig conceptually designed in this study combines a conventional drilling rig with flame jet drilling equipment in a manner that allows use of either system with only a small amount of conversion time. The conventional drilling rig is used to drill through non-spallable overburden and through cement left in the casing after a cementing operation. It can also be used to drill through lower geological zones that are not spallable. The flame jet drilling equipment is used to drill through spallable rock.

The flame jet design concept places a down hole burner system, consisting of a burner and its supporting equipment, on the end of a conventional drill string. The drill string is lowered into the hole by the conventional rig in the same manner that it would lower a conventional drill string and bit. When the drill string is fully in the hole, forward movement is determined by an automatic feed control. Several feed controllers have been patented and are presently in use. Rotary movement of the drill string and burner assembly is accomplished by use of the power swivel to which the drill string is attached. Directional control is accomplished by use of the optional steering equipment described in the report.

Considering the availability of the Con-Cor pipe system and the down hole separator, it should be possible to use any combination of fluids, such as air and diesel fuel or air and propane gas, to achieve a combustible mixture in the event the presently conceived system of combining air, propane, and water does not work. These fluids must, however, be mixed in the proper ratio to achieve ignition. Thus, down hole mixing valves, pulsation dampeners, and a controllable ignition system will be required. The controllable ignition system is necessary to start or stop the burner for tripping operations or for flame-out.

An important aspect of the system that must be considered is that a very large percentage of the air used in this procedure is used for boost air. Thus, the down hole system must be designed so that pure air is vented to the annulus. Therefore, the concept of freely mixing air and propane gas together at the surface mixing valve may not be possible because of the problems of separating these two gases down hole. This problem can, however, be overcome by using Con-Cor pipe.

Another area requiring further investigation is the control of the flowing fluids when pipe is added to the drill string. Under best operating conditions, it takes approximately sixty seconds to perform this function. During that time the jet flame must be turned off or the hole will tend to enlarge at that point. Thus, the effect of and the state of the free flowing propane gas, and the water flowing down the drill pipe must be fully understood. In particular, the propane gas must be controlled to prevent any safety problems. Preliminary investigation indicates that these problems can be controlled with proper valving systems both down hole and at the surface.

Considering the above, it appears that the presently conceived design concept can be made to work. However, the system must be completely analyzed and well-engineered first, particularly in the area of the down hole burner system. Failure to do this could result in serious trouble.

IV ECONOMIC EVALUATION

The newly conceived flame jet design will be economically evaluated by incorporating the design into the comparative drilling economic model. This is completed as noted in Appendices A, B, and C, and the results tabulated in Table 2 under the column titled "Computed, Problem Free, Drilling Cost." As originally stated, the economic model does not make any allowance for maintenance or drilling problems because of the difficulty of quantifying these costs. Thus, an estimated maintenance and problem cost factor must be added to the model data. This factor is estimated to be 40% of the total well cost. This percentage is lower than the average 50% noted for HDR wells EE-2 and EE-3. However, it must be assumed that, if drilling was to continue in the HDR program, the drilling efficiency would improve and problem cost would be reduced. Thus, the 40% cost factor appears to be realistic.

Evaluation of the flame jet design indicates that Con-Cor pipe and/or steering equipment may be required. Several variations of the economic model were run to consider use of these items. These variations are noted as Cases I, II, III, and IV. The equipment used for each case is defined in the equipment description column.

Both of the above factors are tabulated in Table 2 in conjunction with the economic data of the conventional drilling model. The total well costs of both drilling methods are then compared to determine cost reductions.

Analysis of the data indicates that a drilling operation cost reduction of 45% to 49% can be obtained by using this system when drilling a 15,000 ft. hole in the specific type of structure indicated in Figure 1. Further, the advantages of flame jet drilling become effective below approximately 3200 feet when using equipment of this size.

The cost reductions noted can be attributed to the high penetration rate of the flame jet system, the long operational periods of time that the equipment can operate in the hole, and the ensuing reduction of trips. Penetration rates used in this study are based upon actual field data. If, however, lower rates were used, the cost reductions would be lower.

COMPARATIVE COST ANALYSIS

Table 2

Case	Equipment Description	Computed Prob. Free Drilling Cost (60%) ($)	Estimated Maint. & Prob. Cost (40%) ($)	Total[1] Well Cost (100%) ($)	Cost[2] Reduction (%)
• Conventional Drlg.	Standard Drilling Equipment	$3,241,044	$2,160,696	$5,401,740	--
• Flame Jet Drlg.					
Case I	Propane, Conv. Pipe, No Steering Tools	1,657,704	1,105,136	2,762,840	48.9
Case II	Propane, Conv. Pipe, Steering Tools	1,705,944	1,137,296	2,843,240	47.4
Case III	Propane, Con-Cor Pipe, No Steering Tools	1,732,334	1,154,889	2,887,223	46.6
Case IV	Propane, Con-Cor Pipe, Steering Tools	1,780,574	1,187,049	2,967,623	45.1

Notes:

1. Summation of problem free drilling cost and estimated maintenance and problem cost.
2. Percent reduction in cost of Flame Jet Drilling operations as compared to conventional drilling operations.

V SUMMARY

A preliminary technical and economic evaluation of the conceptual flame jet design conceived by LANL has been made. The economic evaluation indicates that it is less expensive to drill granite type structures with conventional equipment of the size used in this report (15,000 feet capability) to depths of approximately 3200 feet. Below this depth, the use of flame jet equipment sharply reduces the cost of drilling. This cost reduction is primarily due to the high penetration rate of the flame jet system, the length of time the equipment can operate in the hole, and the ensuing reduction of the number of trips.

The technical evaluation indicates that the LANL design can probably be made to function properly and effectively. However, it is essential that the transportation system and the down hole burner system be thoroughly analyzed to fully understand the fluid flow and thermodynamic problems involved. Further, it is necessary to design engineer the system so that it will reliably handle the required fluid flows in the confined areas of the down hole systems and during all the required drilling operations. After the above work is completed, the system should be fully tested prior to being used in the field. Failure to do these studies could result in serious problems.

In summary, the LANL system is a unique method for operating a flame jet system. The design concept can probably be made to work effectively, in which case drilling operation costs for certain types of hard rock structures can be reduced significantly.

APPENDIX A

DRILLING TIME AND COST CATEGORIES

Category - 1.00

Title - Road Location and Site Preparation

Definition - Location and preparation of access roads to the drilling site, development of the drilling site and drilling pad, digging and lining reserve mud pits, and other activities required prior to doing any drilling operations.

Time - Time is not considered. This operation is a direct cost item.

Cost - The costs involved in road location and site preparation vary widely from location to location. For this study, an average cost of $50,000 will be used.

Category - 2.00

Title - Initiation

Definition - The drilling of a large diameter, shallow hole over the well site so as to stabilize surface ground material. The hole is cased with the surface conductor pipe. In addition, the mouse hole and the rat hole are also drilled. These operations are performed by a small rig prior to the rig up of the main drilling rig.

Time - Time can vary from location to location. For this study an average time of 72 hours will be used.

Cost - Because of time variations, costs involved will also vary. However, for this study an average cost of $15,000 will be used. In addition to this cost, the cost of the surface conductor must be considered, as well as the cost of cementing and services. These costs are noted in their respective categories.

Category - 3.00

Title - Rig Movement

Definition - Moving the rig from one drilling site to another, preparing the rig for drilling (rig up), and dismantling the rig (rig down) after completion of drilling operations.

Time - Conventional drilling rigs of the size needed for this operation require three days moving time, three days rig up time, and three days rig down time. Rig moving time will be included in the mobilization category. Total time is 216 hours.

The flame jet equipment required for this design will be either owned by the contractor or leased from suppliers. Equipment owned by the contractor can be transported with the conventional rotary drilling equipment. Leased equipment can be obtained as required. Rig up and rig down time for flame jet equipment is estimated to be eight hours for each operation.

Cost - For this study, conventional rig up costs, which include moving time, are estimated to be \$100,000. This includes all truck rentals, special labor, rig crew costs, etc. Rig down costs are estimated to be \$45,000.

Flame jet moving and rig up costs are estimated to be \$10,000. Rig down costs are estimated to be \$5,000

Category - 4.00

Title - Rig Operating Costs

Definition - The hourly or daily rental rates charged by the rig owner (contractor) for use of the rig. These rates include charges for labor, rig replacement costs, insurance, finance charges, taxes, general and administrative costs, and profit.

Time - The rates are charged on either an hourly or daily rate.

Costs - For this study, the conventional rotary rig required to drill the wells in question is estimated to cost $5,442,550. During normal operating times, the following average charges would be made:

Day Rate with Pipe	- $8160	($340/hr)
Day Rate without Pipe	- $7200	($300/hr)
Standby Rate (normal)	- $4800	($200/hr)
Day Rate for use with Flame Jet Rig	- $6000	($250/hr)

Considering the estimated cost of the flame jet rig designed in this study in $161,500, the following charges for its use are estimated to be:

Day Rate	- $1200	($50/hr)
Standby Rate	- $ 720	($30/hr)

It should be noted that all of the above rates will change from location to location due to labor and tax variations.

Included in this overall category are several operations that relate to specific flame jet procedures. The first operation, Flame Jet Rig Conversion, refers to the operations required to change from rotary rig drilling procedures to flame jet procedures. This operation includes the installation of the power sub and the circulation control valve, assembling the down hole tools, etc. No direct costs are incurred, but the operation is estimated to take four hours.

Flame Jet Maintenance refers to repairing and/or maintaining the components of the flame jet bottom hole assembly. Costs are estimated to be $200 per operation. The time involved is estimated to be two hours per operation.

Flame Jet Bottom Hole Assembly (BHA) Change refers to the actual changing of components in the BHA. This operation is estimated to take two hours. No direct costs are incurred.

Category - 5.00

Title - Fuel

Definition - The diesel fuel required to operate the generator sets.

Time - The costs are based on an hourly rate.

Cost - Fuel cost is estimated to be $.91/gal. Assume the conventional rig has three D398 diesel generator sets operating at 1200 RPM and 60 cycles. Continuous electrical power output will be 565 KW per generator set. Fuel consumption at this rate of operation is 45 gal/hr for each generator set. Assuming the above cost and operating levels, fuel consumption and cost for the various rig operations is as noted in Table 1-A

Fuel costs are based on Northern New Mexico delivery rates.

FUEL COSTS

Table 1-A

OPERATION	POWER REQUIREMENT (Average)	FUEL CONSUMPTION gal/hr	FUEL COST $/gal	FUEL COST $/hr
Conventional Rig:				
Non-Drilling Operations	1 Gen. Set Operationg at 1/3 Power	15	.91	14
Drilling Operations	3 Gen. Sets Operating at 1/3 Power	45	.91	41
Tripping 0' - 4,999'	3 Gen. Sets Operating at 1/3 Power	45	.91	41
5,000' - 9,999'	3 Gen. Sets Operating at 2/3 Power	90	.91	82
10,000' - 15,999'	3 Gen. Sets Operating at Full Power	135	.91	123
Standby Conventional Drlg.	1 Gen. Set Operating at 1/3 Power	15	.91	14
Standby Flame Jet Drlg.	1 Gen. Set Operating at 1/2 Power	23	.91	21
Flame Jet Drilling:				
Non-Drilling Operations	1 Gen. Set Operating at 1/2 Power	23	.91	21
Drilling Operations	1 Gen. Set Operating at 1/2 Power, + 85 gal/hr for Air Compressor Sys.	108	.91	98
Tripping 0' - 4,999'	3 Gen. Sets Operating at 1/3 Power	45	.91	41
5,000' - 9,999'	3 Gen. Sets Operating at 2/3 Power	90	.91	82
10,000' - 15,999'	3 Gen. Sets Operating at Full Power	135	.91	123

Category - 6.00

Title - Transportation and Miscellaneous

Definition - Truck transportation costs for both normal and daily supplies, and for rig maintenance activities. Charges for miscellaneous services and equipment required for rig operation are also included.

Time - The costs are based on an hourly rate.

Costs - Average costs for a 25 to 30 day drilling operation normally are $50,000 to $70,000. This equates to an average hourly rate of $90 for conventional rotary drilling operations.

Flame jet drilling rates are considerably lower due to the simplicity of the operation. However, because a large part of the conventional drilling rig is used with the flame jet rig, supplies and maintenance of that equipment must be considered. Thus an average rate of $50/hr will be used.

Category - 7.00

Title - Rental

Definition - Charges for rental items that are not expensive enough to be treated individually, such as surveying collars, special BOP components, small compressors, etc. In addition, for this study, down hole motor, sensor, and steering tool rates will also be included.

Time - The costs are based on an hourly rate.

Cost - An average charge of $50/hr will be used for conventional drilling operations. For flame jet operations, an average hourly charge of $10 will be used. In addition, use of down hole motors will be charged at $200/hr for a 6-1/2" unit and $210/hr for a 7-3/4" unit. Steering tools and equipment will be charged at $170/hr.

Considering the above, the following combination of rental charges will be used in this study.

Conventional drilling rig:

Normal rental charges	- $ 50/hr
Normal rental charges, plus use of 6-1/2" motor	- $250/hr
Normal rental charges, plus use of 7-3/4" motor	- $260/hr

Flame Jet rig:

Normal rental charges	- $ 10/hr
Normal rental charges, plus use of sensor and steering tools	- $180/hr

Category - 8.00

Title - Supervision

Definition - Company (not contractor) overhead costs for part-time supervision on a rig. This charge can also include costs for a company geologist.

Time - The costs are based on an hourly rate.

Costs - These costs vary from area to area and are based on the difficulty of drilling and whether drilling is in an exploration or production area.

For the purpose of this report, an average daily rate of $500 per eight hour shift will be used. Considering that 1-1/2 shifts per day will probably be required, and that the rig will operate 24 hours per day, the actual rate (for a 24 hour day) will be $31/hr. This rate will be used for both conventional and flame jet operations.

Category	- 9.00
Title	- Water
Definition	- Water required for cementing operations, mud operations, rig wash down, etc. In addition, in flame jet operations water is used in the down hole operation.
Time	- Costs are based on an hourly rate for flame jet operations and a fixed rate for conventional rig operations.
Costs	- For conventional rig operations in New Mexico assume:

Total water required, each well	-
Truck (148 bbl cap.), transportation rate	- \$57.08/hr
Average hours per truck trip	- 4
Cost of water	- \$ 0.10/bbl

Considering the above, Total water charges are	- \$6600
Estimated water disposal charges	- \$6000
Water charges, flame jet operations	- \$49.00/hr

Category - 10.00

Title - Propane

Definition - The propane gas used in the combustion process of the flame jet drilling operation.

Time - Costs are based on an hourly rate.

Cost - Use of propane gas entails two cost factors. The first is the cost of the on-site storage tank and facility. This equipment has a one time set up charge of $17,000 which includes placement of a storage tank foundation, an 18,000 gal storage tank, piping, controls, safety equipment, etc. Assuming this equipment is left on site for a period of two months, and a 24 hour operating day is used, the average hourly rate is $12/hr.

The second factor is the cost of propane gas. Assuming a delivered cost of $.62/gal, and an estimated use of 72 gal/hr, the hourly cost of propane gas is approximately $45/hr.

Combining the two cost factors, the use of propane gas can be approximated to cost $57/hr.

Category - 11.00

Title - Mud

Definition - The additives mixed with the circulating fluid.

Time - For this report, all chemical additives will be pro-rated on an hourly basis.

Cost - In both models, chemicals and solids are added to the drilling fluids. Solids are added only in the nongranitic rock formations. Chemicals are added during all drilling operations.

Model 1, Solids Volume and Cost

Fluid volume - 1540 bbls

Vol. of mud to raise water to 9.6#/gal is 75 100# sacks barrite/100 bbls fluid

No. sacks required: 75 x 15.40 = 1155

Cost of barrite @ $6.00/sack: $6,930

Assume $20.00/hr average cost

Model 2, Solids Volume and Cost

Fluid volume - 1409 bbls

Vol. of mud to raise water to 9.2#/gal is 59 100# sacks barrite/100 bbls fluid

No. sacks required: 59 x 14.09 = 831

Cost of barrite @ $6.00/sack: $4,986

Assume $20.00/hr average cost

Models 1 and 2, Chemical Costs

Assume $3.00/hr of operation

Average hourly costs to be used

Nongranitic rock - $23.00

Granitic rock - $ 3.00

Category - 12.00

Title - Bits

Definition - The cutting tool attached to the bottom of the drill pipe.

Time - Regardless of the type of bit being used, an average change time of one hour shall be used.

Cost - Average bit prices shall be used as follows:

26" hole - 3 cutter, steel, milled tooth, nonsealed bearing

Cost - $12,930

17-1/2" hole - 3 cutter, steel, milled tooth, nonsealed bearing

Cost - $4,947

12-1/2" hole - Tungsten carbide insert, sealed journal bearing

Cost - $8,414

8-3/4" hole - Tungsten carbide insert, sealed journal bearing

Cost - $4,347

Category - 13.00

Title - Bottom Hole Assembly

Definition - The components (stabilizers, drill collar, shock subs, etc.) incorporated into the bottom of the drill string.

Time - Regardless of the components being changed, an average change time of two hours shall be used.

Cost - Regardless of the components being changed, an average cost of $1,000 per bit change shall be used.

Category - 14.00

Title - Tripping

Definition - The operation of running the drill pipe or the flame jet into or out of the hole

Time - For this report, the following average hourly factors will be used.

Pipe - Conventional Rig:

0' - 4,999'	- 1.50
5,000' - 9,999'	- 3.50
10,000' - 15,999'	- 7.00

Pipe - Flame Jet Rig:

0' - 4,999'	- 1.50
5,000' - 9,999'	- 3.50
10,000' - 15,999'	- 7.00

Cost - No cost factors are involved with this operation.

Category - 15.00

Title - Logging

Definition - Logging includes all measurements and analytical techniques relating to the down hole geological evaluation.

Time - Logging time includes all of the time required to take measurements in the hole, the trip times, and the time to rig up and rig down the equipment involved. For this report, the following hourly factors will be used.

Rig Up	- 2.00
Rig Down	- 1.00
Tripping, In or Out	
0' - 4,999'	- 1.00
5,000' - 9,999'	- 1.50
10,000' - 15,999'	- 2.00
Logging Time, Average	- 24.00

Cost - Costs reflect all logging company charges, including travel, setup, logging, temperature penalties, etc. For this report, the following average cost will be used.

Logging	- $2,000

Category - 16.00

Title - Surveying

Definition - Surveying includes all measurements and analytical techniques relating to the directional program of a well.

Time - Surveying includes all the time required to make measurements in the hole, the trip times, etc. For this report, the following hourly rates will be used.

Trip In, Trip Out, Survey

0' - 4,999'	- 2.00
5,000' - 9,999'	- 3.00
10,000' - 15,999'	- 4.00

Cost - No cost factors are involved because all equipment is owned by the drilling company.

Category - 17.00

Title - Drilling

Definition - Rotary drilling refers to the time spent with the drill bit rotating on the bottom of the hole. Reaming refers to the time spent straightening or enlarging the hole. Flame jet drilling refers to the time spent drilling the hole with the flame jet.

Time - For this report, all time factors will be average hourly rates as follows.

Conventional Rotary Rig:

Rotary Drilling,	nongranitic rock	- 8
	granitic rock	- 6
	cement	- 11
Reaming,	nongranitic rock	- 8
	granitic rock	- 6
Turbo Drilling,	granitic rock	- 15
Coring		- 6

Flame Jet Rig:

0' - 4,999'	- 50
5,000' - 9,999'	- 70
10,000' - 15,999'	- 90

Cost - Cost factors involved with these operations are noted under the appropriate category listings.

Category - 18.00

Title - Wellhead

Definition - The time and equipment costs involved in the installation of the wellhead components.

Time - The time required to remove and re-attach the blowout preventer components, and install the necessary wellhead equipment. For this report, the average hourly time used shall be 12 hours.

Cost - The costs vary depending upon the size of the casing string involved. The following average costs will be used.

20" Casing	- $17,000
13-3/8" Casing	- $16,000
9-5/8" Casing	- $15,000

Category - 19.00

Title - Special Equipment

Definition - The utilization of special pieces of equipment, as needed, such as additional air compressors, mufflers, flow lines, etc.

Time - For this report, the utilization costs of the components involved are all based on an hourly rate.

Costs - The costs used will be those directly charged by the vendor involved.

Flame Jet Drilling, Air:

Air Compressor System	\$2000/day (\$85/hr)

Category - 20.00

Title - Casing

Definition - The operational efforts and steel pipe used to prevent the walls of a hole from sloughing off or caving in.

Time - Time factors relate primarily to operational activities. Considering actual field operations, the following average hourly factors will be used.

Rig Up	- 2.00
Rig Down	- 2.00
Running Casing (hrs/1000 ft)	
20 in	- 3.50
13-3/8 in	- 3.00
9-5/8 in	- 3.00
Liner Hanging	- 3.00
Prepare to Run Casing	- 24.00

Cost - Cost factors are based upon actual costs of casing and average cost of tools and services. Casing costs are based upon 100' lengths and include connectors. No discounts are noted. Tools and services include cost of scratchers, centralizers, special tools, etc. The following costs will be used for Models 1 and 2.

Casing, Model 1 ($/100')

Conductor Pipe	- $ 5,800
Surface Casing, 20" - 133#, K-55	- 8,417
Inter. Casing, 13-3/8" - 54-1/2#, K-55	- 2,882
Final Casing, 9-5/8" - 40#, N-80	- 2,723

Casing, Model 2 ($/100')

Conductor Pipe	- 5,800
Surface Casing, 20" - 133#, K-55	- 8,417
Inter. Casing, 13-3/8" - 72#, N-80	- 4,775
Final Casing, 9-5/8" - 47#, P-110	- 3,674

Tools and Services (Average Cost, $)

Conductor Pipe	- $ 3,500
Surface Casing	- 5,000
Inter. Casing	- 7,000
Final Casing	- 10,000

Category - 21.00

Title - Cement

Definition - The operational efforts and materials used to fix the casing firmly in the hole.

Time - Time factors relate primarily to operational activities. Considering actual field operations, the following average hourly factors will be used.

Rig Up	- 2
Rig Down	- 1
Cementing	
0' - 4,999'	- 3
5,000' - 9,999'	- 6
10,000' - 15,999'	- 9
WOC/Test	- 18
Cement Testing	- 6

Cost - Cost factors are based upon average costs of cement, equipment, and services. No discounts are included. For Models 1 and 2, the following costs will be used.

Cement, Model 1	
Conductor Pipe	- $5,500
Surface Casing, 2300 sacks	- 9,200
Inter. Casing, 2300 sacks	- 9,200
Final Casing, 237 sacks	- 950

Cement, Model 2

Conductor Pipe	- $ 5,500
Surface Casing, 3050 sacks	- 12,200
Inter. Casing, 1200 sacks	- 4,800
Final Casing, 2500 sacks	- 10,000

Equipment

Surface Casing	- $ 5,000
Inter. Casing	- 10,000
Final Casing	- 12,000

Services (including mileage)

0' - 4,999'	- $ 2,000
5,000' - 9,999'	- 3,000
10,000' - 15,999'	- 4,000

APPENDIX B

VARIABLE COST CATEGORIES ANALYSIS

VARIABLE COST

CONVENTIONAL ROTARY DRILLING, CONV1 & CONV2

Table 1-B

Data Category	4.03	5.01	6.01	7.01	8.01	11.01	
Activity	Conv. Rig Operation Rate ($/hr.)	Fuel Cost ($/hr.)	Trans. & Misc. Cost ($/hr.)	Rental Cost ($/hr.)	Supervision Cost ($/hr.)	Mud Cost ($/hr.)	Total Cost ($/hr.)
Nondrilling Operations:	340	14	90	50	31	0	525
Drilling Operations:							
Nongranitic Rock	340	41	90	50	31	23	575
Granitic Rock w/Turbin	340	41	90	250	31	3	555
Granitic Rock wo/Turbin	340	41	90	50	31	3	555
Tripping:							
0' - 4,999'	340	41	90	50	31	0	552
5,000' - 9,999'	340	82	90	50	31	0	593
10,000' - 15,999'	340	123	90	50	31	0	634

VARIABLE COST

FLAME JET DRILLING, FLJET1

MODEL 2, CASE I

Table 2-B-1

Data Category	4.05	4.02	5.01	6.02	7.02	8.02	9.02	10.01	19.01	
Activity	Fl. Jet Operation Rate ($/hr.)	Conv. Rig Standby Rate ($/hr.)	Fuel Cost ($/hr.)	Trans. & Misc. Cost ($/hr.)	Rental Cost ($/hr.)	Supervision Cost ($/hr.)	Water Cost ($/hr.)	Propane Cost ($/hr.)	Sepc. Equip. ($/hr.)	Total Cost ($/hr.)
Nondrilling Operations:	50	250	21	50	10	31	0	0	85	497
Drilling Operations:										
With Propane	50	250	98	50	10	31	49	57	85	680
Tripping:										
0' - 4,999'	50	250	41	50	10	31	0	0	85	517
5,000' - 9,999'	50	250	82	50	10	31	0	0	85	558
k0,000' - 15,999'	50	250	123	50	10	31	0	0	85	599

VARIABLE COST

FLAME JET DRILLING, FLJET1

MODEL 2, CASE II

Table 2-B-2

Data Category	4.05	4.02	5.01	6.02	7.02	8.02	9.02	10.01	19.01	
Activity	Fl. Jet Operation Rate ($/hr.)	Conv. Rig Standby Rate ($/hr.)	Fuel Cost ($/hr.)	Trans. & Misc. Cost ($/hr.)	Rental Cost ($/hr.)	Supervision Cost ($/hr.)	Water Cost ($/hr.)	Propane Cost ($/hr.)	Spec. Equip. ($/hr.)	Total Cost ($/hr.)
Nondrilling Operations:	50	250	21	50	180	31	0	0	85	667
Drilling Operations:										
With Propane	50	250	98	50	180	31	49	57	85	850
Tripping:										
0' - 4,999'	50	250	41	50	180	31	0	0	85	687
5,000' - 9,999'	50	250	82	50	180	31	0	0	85	728
10,000' - 15,999'	50	250	123	50	180	31	0	0	85	769

VARIABLE COST

FLAME JET DRILLING, FLJET1

MODEL 2, CASE III

Table 2-B-3

Data Category	4.05	4.02	5.01	6.02	7.02	8.02	9.02	10.01	19.01	
Activity	Fl. Jet Operation Rate ($/hr.)	Conv. Rig Standby Rate ($/hr.)	Fuel Cost ($/hr.)	Trans. & Misc. Cost ($/hr.)	Rental Cost ($/hr.)	Supervision Cost ($/hr.)	Water Cost ($/hr.)	Propane Cost ($/hr.)	Spec. Equip. ($/hr.)	Total Cost ($/hr.)
Nondrilling Operations:	300	250	21	50	10	31	0	0	85	747
Drilling Operations:										
With Propane	300	250	98	50	10	31	49	57	85	930
Tripping:										
0' - 4,999'	300	250	41	50	10	31	0	0	85	767
5,000' - 9,999'	300	250	82	50	10	31	0	0	85	839
10,000' - 15,999'	300	250	123	50	10	31	0	0	85	911

VARIABLE COST

FLAME JET DRILLING, FLJET1

MODEL 2, CASE IV

Table 2-B-4

Data Category	4.05	4.02	5.01	6.02	7.02	8.02	9.02	10.01	19.01	
Activity	Fl. Jet Operation Rate ($/hr.)	Conv. Rig Standby Rate ($/hr.)	Fuel Cost ($/hr.)	Trans. & Misc. Cost ($/hr.)	Rental Cost ($/hr.)	Supervision Cost ($/hr.)	Water Cost ($/hr.)	Propane Cost ($/hr.)	Spec. Equip. ($/hr.)	Total Cost ($/hr.)
Nondrilling Operations:	300	250	21	50	180	31	0	0	85	917
Drilling Operations										
With Propane	300	250	98	50	180	31	49	57	85	1100
Tripping:										
0' - 4,999'	300	250	41	50	180	31	0	0	85	937
5,000' - 9,999'	300	250	82	50	180	31	0	0	85	1009
10,000' - 15,999'	300	250	123	50	180	31	0	0	85	1081

VARIABLE COST

CONVENTIONAL ROTARY DRILLING, FLJET1 & FLJET2

Table 3-B

Data Category	4.03	4.09	5.01	6.01	7.01	8.01	11.01	
Activity	Conv. Rig Operation Rate ($/hr.)	Fl. Jet Standby Rate ($/hr.)	Fuel Cost ($/hr.)	Trans. & Misc. Cost ($/hr.)	Rental Cost ($/hr.)	Supervision Cost ($/hr.)	Mud Cost ($/hr.)	Total Cost ($/hr.)
Nondrilling Operations:	340	30	14	90	50	31	0	555
Drilling Operations:								
Nongranitic Rock	340	30	41	90	50	31	23	605
Granitic Rock	340	30	41	90	50	31	3	585
Tripping:								
0' - 4,999'	340	30	41	90	50	31	0	582
5,000' - 9,999'	340	30	82	90	50	31	0	623
10,000' - 15,999'	340	30	123	90	50	31	0	664

APPENDIX C

OPERATION TIME, DIRECT COST, AND VARIABLE COST DATA

"DATA"

Flame Jet and Conventional Drilling Activities
Operation Time, Direct Cost, and Variable Cost Data
Model 1 and Model 2

Dir. Cost Op Time Category	Activity	Mod 1 Dir Cost ($)	Mod 1 Op Time (Hrs.)	Mod 2 Dir Cost ($)	Mod 2 Op Time (Hrs.)
1.00	Road Location & Site Preparation (Total $)	50000	-	50000	-
2.00	Initiation (Total $)	15000	72.00	15000	72.00
3.00	Rig Movement (Total $)				
3.01	Rotary Rig Mobilization (Rig Up)	100000	144.00	100000	144.00
3.02	Rotary Rig Demobilization (Rig Down)	45000	72.00	45000	72.00
3.03	Fl. Jet Rig Design No. 1 Mobil.	10000	8.00	40000	96.00
3.04					
3.05					
3.06					
3.07	Fl. Jet Rig Design No. 1 Demobil.	5000	8.00	15000	48.00
3.08					
3.09					
3.10					
4.00	Rig Operating Rates ($/Hr.)				
4.01	Rotary Rig Standby - Conventional Rig	200	-	200	-
4.02	Rotary Rig Standby - Flame Jet Rig	250	-	250	-
4.03	Rotary Rig Hourly with Pipe	340	-	340	-
4.04	Rotary Rig Hourly without Pipe	300	-	300	-
4.05	Fl. Jet Rig Des. No. 1 Hourly	50	-	360	-
4.06					
4.07					
4.08					
4.09	Fl. Jet Rig Des. No. 1 Standby	30	-	210	-
4.10					
4.11					
4.12					
4.13	Flame Jet Rig Design No. 1 Conversion	-	4.00	-	12.00
4.14					
4.15					
4.16					
4.17	Flame Jet Rig Maintenance	-	2.00	-	2.00
4.18	Flame Jet RIg Maintenance Parts	200	-	200	-
4.19	Flame Jet Rig BHA Change	-	2.00	-	2.00
5.00	Fuel Cost ($/Hr.)				
5.01	Fuel	*	-	*	-
5.02					
5.03					
5.04					

Variable Cost Category	Activity	Variable Cost ($/Hr.)
	Conventional Drlg., CONV1 & CONV2	
VC-01	Nondrlg. Oper.	525
	Drlg. Oper.:	
VC-02	Nongranitic Rock	575
VC-03	Granitic Rock, w/Turbin	555
VC-04	Granitic Rock, wo/Turbin	555
	Tripping:	
VC-05	0' - 4999'	552
VC-06	5000' - 9999'	593
VC-07	10000' - 15999'	634
	Flame Jet Drlg., FLJET1 & FLJET2	
VC-10	Nondrlg. Oper.	497
VC-11	Drlg. Oper.:	
VC-11	With Oxygen	623
VC-12	With Air	680
	Tripping	
VC-13	0' - 4999'	517
VC-14	5000' - 9999'	558
VC-15	10000' - 15999'	599
	Conventional Drlg., FLJET1 & FLJET2	
VC-20	Nondrlg. Oper.	555
	Drlg. Oper.:	
VC-21	Nongranitic Rock	605
VC-22	Granintic Rock	585
	Tripping	
VC-23	0' - 4999'	582
VC-24	5000' - 9999'	623
VC-25	10000' - 15999'	664

Dir. Cost Op Time Category	Activity	Mod 1 Dir Cost ($)	Mod 1 Op Time (Hrs.)	Mod 2 Dir Cost ($)	Mod 2 Op Time (Hrs.)	Variable Cost Category	Activity	Variable Cost ($/Hr.)
6.00	Transportation & Miscellaneous Cost ($/Hr.)							
6.01	Rotary Rig	90	-	90	-			
6.02	Flame Jet Rig Design No. 1	50	-	45	-			
6.03								
6.04								
6.05								
6.06								
6.07								
6.08								
6.09								
7.00	Rental Cost ($/Hr.)							
7.01	Rotary Rig	*	-	*	-			
7.02	Flame Jet Rig Design No. 1	*	-	*	-			
7.03								
7.04								
7.05								
8.00	Supervision Cost ($/Hr.)							
8.01	Rotary Rig	31	-	31	-			
8.02	Flame Jet Rig Design No. 1	31	-	31	-			
8.03								
8.04								
8.05								
9.00	Water Cost							
9.01	Rotary Rig (Total $)	6600	-	6600	-			
9.02	Flame Jet Rig Design No. 1 ($/Hr.)	49	-	49	-			
9.03								
9.04								
9.05								
9.06	Water Disposal (Total $)	6000	-	6000	-			
9.07								
9.08								
9.09								
9.10								
10.00	Propane Cost ($/Hr.)							
10.01	Propane	*	-	*	-			
10.02								
10.03								
11.00	Mud Cost							
11.01	Mud Cost ($/Hr.)	*	-	*	-			
11.02	Mud Conditioning (Total $ & Average Hrs.)	500	3	500	3			
11.03								
12.00	Bits							
12.01	Bit Change (Average Hrs.)	-	1.00	-	1.00			
12.02	Bit Cost 26" Hole (Total $)	12930	-	12930	-			
12.03	Bit Cost 17 1/2" Hole (Total $)	4947	-	4947	-			
12.04	Bit Cost 12 1/2" Hole (Total $)	8414	-	8414	-			
12.05	Bit Cost 8 3/4" Hole (Total $)	4347	-	4347	-			
13.00	Bottom Hole Assembly (BHA)							
13.01	BHA Change (Average Hrs.)	-	2.00	-	2.00			
13.02	BHA Cost (Total $)	1000	-	1000	-			
13.03								
13.04								

Dir. Cost Op Time Category	Activity	Mod 1 Dir Cost ($)	Mod 1 Op Time (Hrs.)	Mod 2 Dir Cost ($)	Mod 2 Op Time (Hrs.)	Variable Cost Category	Activity	Variable Cost ($/Hr.)
14.00	Tripping In or Out (Average Hrs.)							
	Pipe - Conventional Rig							
14.01	0'-4999'	-	1.50	-	1.50			
14.02	5000'-9999'	-	3.50	-	3.50			
14.03	10000'-15999'	-	7.00	-	7.00			
	Umbilical - Flame Jet Design No.1							
14.04	0'-4999'	-	1.50	-	1.50			
14.05	5000'-9999'	-	3.50	-	3.50			
14.06	10000'-15999'	-	7.00	-	7.00			
15.00	Logging (Total $ & Average Hrs.)							
15.01	Rig Up	-	2.00	-	2.00			
15.02	Rig Down	-	1.00	-	1.00			
	Trip In or Trip Out							
15.03	0'-4999'	-	1.00	-	1.00			
15.04	5000'-9999'	-	1.50	-	1.50			
15.05	10000'-15999'	-	2.00	-	2.00			
15.06	Logging Cost and Time	2000	24.00	2000	24.00			
15.07								
15.08								
15.09								
15.10								
16.00	Surveying (Average Hrs.)							
	Trip In/Trip Out, Survey							
16.01	0'-4999'	-	2.00	-	2.00			
16.02	5000'-9999'	-	3.00	-	3.00			
16.03	10000'-15999'	-	4.00	-	4.00			
16.04								
16.05								
16.06								
16.07								
16.08								
16.09								
16.10								
17.00	Drilling (Feet/Hr.)							
	Conventional Rig							
17.01	Rotary Drilling: Nongranitic Rock	-	8.00	-	8.00			
17.02	Granitic Rock	-	6.00	-	6.00			
17.03	Cement	-	11.00	-	11.00			
17.04	Reaming: Nongranitic Rock	-	8.00	-	8.00			
17.05	Granitic Rock	-	6.00	-	6.00			
17.06	Turbo Drilling: Granitic Rock	-	15.00	-	15.00			
17.07	Coring	-	6.00	-	6.00			

Dir. Cost Op Time Category	Activity	Mod 1 Dir Cost ($)	Mod 1 Op Time (Hrs.)	Mod 2 Dir Cost ($)	Mod 2 Op Time (Hrs.)	Variable Cost Category	Activity	Variable Cost ($/Hr.)
	Flame Jet Rig							
17.08	0'-4999'	-	50	-	50			
17.09	5000'-9999'	-	70	-	70			
17.10	10000' - 15999'	-	90	-	90			
18.00	Well Head							
18.01	Installation (Average Hrs.)	-	12.00	-	12.00			
18.02	Equipment Cost 20" Casing (Total $)	17000	-	17000	-			
18.03	Equipment Cost 13 3/8" Casing (Total $)	16000	-	16000	-			
18.04	Equipment Cost 9 5/8" Casing (Total $)	15000	-	15000	-			
18.05								
18.06								
18.07								
18.09								
18.10								
19.00	Special Equipment							
19.01	Equipment Cost ($/Hr.)	*	-	*	-			
19.02								
19.03								
19.04								
19.05								
19.06								
19.07								
19.08								
19.09								
19.10								
20.00	Casing							
	Operations							
20.01	Rig Up (Average Hrs.)	-	2.00	-	2.00			
20.02	Rig Down (Average Hrs.)	-	2.00	-	2.00			
	Running Casing (Average Hrs./1000 Ft.)							
20.03	20 in.	-	3.50	-	3.50			
20.04	13-3/8 in.	-	3.00	-	3.00			
20.05	9-5/8 in.	-	3.00	-	3.00			
20.06	Liner Hanging (Average Hrs.)	-	3.00	-	3.00			
20.07	Prepare to Run Casing (Average Hrs.)	-	24.00	-	24.00			
	Cost							
	Conductor							
20.08	Casing ($/100')		-		-			
20.09	Tools & Service (Total $)		-		-			
	Surface Casing							
20.10	Casing ($/100')	8417	-	8417	-			
20.11	Tools & Service (Total $)	5000	-	5000	-			
	Intermediate Casing							
20.12	Casing ($/100')	2882	-	4775	-			
20.13	Tools & Service (Total $)	7000	-	7000	-			
	Second Intermediate Casing							
20.14	Casing ($/100')	-	-	-	-			
20.15	Tools & Service (Total $)	-	-	-	-			

Dir. Cost Op Time Category	Activity	Mod 1 Dir Cost ($)	Mod 1 Op Time (Hrs.)	Mod 2 Dir Cost ($)	Mod 2 Op Time (Hrs.)	Variable Cost Category	Activity	Variable Cost ($/Hr.)
	Final Casing							
20.16	Casing ($/100')	2723	-	3674	-			
20.17	Tools & Service (Total $)	10000	-	10000	-			
21.00	Cementing							
	Operations (Average Hrs.)							
21.01	Rig Up	-	2.00	-	2.00			
21.02	Rig Down	-	1.00	-	1.00			
	Cementing - (Average Hrs.)							
21.03	0'-4999'	-	3.00	-	3.00			
21.04	5000'-9999'	-	6.00	-	6.00			
21.05	10000'-15999'	-	9.00	-	9.00			
21.06	WOC/Test	-	18.00	-	18.00			
21.07	Cement Testing	-	6.00	-	6.00			
	Cost (Total $)							
	Conductor							
21.08	Cement		-		-			
21.09	Equipment		-		-			
21.10	Service		-		-			
	Surface Casing							
21.11	Cement	9200	-	12200	-			
21.12	Equipment	5000	-	5000	-			
21.13	Service	2000	-	2000	-			
	Intermediate Casing							
21.14	Cement	9200	-	4800	-			
21.15	Equipment	10000	-	10000	-			
21.16	Service	2000	-	2000	-			
	Second Intermediate Casing							
21.17	Cement	-	-	-	-			
21.18	Equipment	-	-	-	-			
21.19	Service	-	-	-	-			
	Final Casing							
21.20	Cement	950	-	10000	-			
21.21	Equipment	12000	-	12000	-			
21.22	Service	4000	-	4000	-			

APPENDIX D

DRILLING MODELS

"CONV1"

Conventional Rig
Drilling
Model No. 1

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
12.	Trip In - New Bit	202.00		14.01	1.50	VC-05	828.00	12.02	12930.00	1.50	13758.00
13.	Drill	604.00	402.00	17.01	50.25	VC-02	28893.75	.00	.00	51.75	42651.75
14.	Survey	604.00		16.01	2.00	VC-01	1050.00	.00	.00	53.75	43701.75
15.	Trip Out	604.00		14.01	1.50	VC-05	828.00	.00	.00	55.25	44529.75
16.	Change Bit	604.00		12.01	1.00	VC-01	525.00	12.02	12930.00	56.25	57984.75
17.	Change BHA	604.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	58.25	60034.75
18.	Trip In	604.00		14.01	1.50	VC-05	828.00	.00	.00	59.75	60862.75
19.	Drill	769.00	165.00	17.01	20.63	VC-02	11859.38	.00	.00	80.38	72722.13
20.	Survey	769.00		16.01	2.00	VC-01	1050.00	.00	.00	82.38	73772.13
21.	Drill	938.00	169.00	17.01	21.13	VC-02	12146.88	.00	.00	103.50	85919.00
22.	Survey	938.00		16.01	2.00	VC-01	1050.00	.00	.00	105.50	86969.00
23.	Trip Out	938.00		14.01	1.50	VC-05	828.00	.00	.00	107.00	87797.00
24.	Change Bit	938.00		12.01	1.00	VC-01	525.00	12.02	12930.00	108.00	101252.00
25.	Change BHA	938.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	110.00	103302.00
26.	Trip In	938.00		14.01	1.50	VC-05	828.00	.00	.00	111.50	104130.00
27.	Ream	938.00		17.04	12.50	VC-02	7187.50	.00	.00	124.00	111317.50
28.	Drill	1052.00	114.00	17.01	14.25	VC-02	8193.75	.00	.00	138.25	119511.25
29.	Survey	1052.00		16.01	2.00	VC-01	1050.00	.00	.00	140.25	120561.25
30.	Drill	1174.00	122.00	17.01	15.25	VC-02	8768.75	.00	.00	155.50	129330.00
31.	Survey	1174.00		16.01	2.00	VC-01	1050.00	.00	.00	157.50	130380.00
32.	Drill	1259.00	85.00	17.01	10.63	VC-02	6109.38	.00	.00	168.13	136489.38
33.	Survey	1259.00		16.01	2.00	VC-01	1050.00	.00	.00	170.13	137539.38
34.	Trip Out	1259.00		14.01	1.50	VC-05	828.00	.00	.00	171.63	138367.38
35.	Change Bit	1259.00		12.01	1.00	VC-01	525.00	12.02	12930.00	172.63	151822.38
36.	Change BHA	1259.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	174.63	153872.38
37.	Trip In	1259.00		14.01	1.50	VC-05	828.00	.00	.00	176.13	154700.38
38.	Drill	1540.00	281.00	17.01	35.13	VC-02	20196.88	.00	.00	211.25	174897.25
39.	Survey	1540.00		16.01	2.00	VC-01	1050.00	.00	.00	213.25	175947.25
40.	Drill	1705.00	165.00	17.01	20.63	VC-02	11859.38	.00	.00	233.88	187806.63
41.	Survey	1705.00		16.01	2.00	VC-01	1050.00	.00	.00	235.88	188856.63
42.	Drill	1729.00	24.00	17.01	3.00	VC-02	1725.00	.00	.00	238.88	190581.63
43.	Survey	1729.00		16.01	2.00	VC-01	1050.00	.00	.00	240.88	191631.63
44.	Trip Out	1729.00		14.01	1.50	VC-05	828.00	.00	.00	242.38	192459.63
45.	Change Bit	1729.00		12.01	1.00	VC-01	525.00	12.02	12930.00	243.38	205914.63
46.	Change BHA	1729.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	245.38	207964.63
47.	Trip In	1729.00		14.01	1.50	VC-05	828.00	.00	.00	246.88	208792.63
48.	Drill	1785.00	56.00	17.01	7.00	VC-02	4025.00	.00	.00	253.88	212817.63
49.	Survey	1785.00		16.01	2.00	VC-01	1050.00	.00	.00	255.88	213867.63
50.	Trip Out	1785.00		14.01	1.50	VC-05	828.00	.00	.00	257.38	214695.63
51.	Condition Mud	1785.00		11.02	3.00	VC-01	1575.00	11.02	500.00	260.38	216770.63
52.	Prepare to Run Casing	1785.00		20.07	24.00	VC-01	12600.00	.00	.00	284.38	229370.63
53.	Rig Up Casing Tools	1785.00		20.01	2.00	VC-01	1050.00	.00	.00	286.38	230420.63
54.	Run 20 inch Casing	1785.00		20.03	6.23	VC-05	3438.96	.00	.00	292.61	233859.59
55.	Casing	1785.00		.00	.00	.00	.00	20.10	149822.60	292.61	383682.19
56.	Tools/ Services	1785.00		.00	.00	.00	.00	20.11	5000.00	292.61	388682.19
57.	Rig Down Casing Tools	1785.00		20.02	2.00	VC-01	1050.00	.00	.00	294.61	389732.19
58.	Rig Up Cement Tools	1785.00		21.01	2.00	VC-01	1050.00	.00	.00	296.61	390782.19

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
59.	Cementing	1785.00		21.03	3.00	VC-01	1575.00	.00	.00	299.61	392557.19
60.	Cement	1785.00		.00	.00	.00	.00	21.11	9200.00	299.61	401557.19
61.	Equipment	1785.00		.00	.00	.00	.00	21.12	5000.00	299.61	406557.19
62.	Sevice And Mileage	1785.00		.00	.00	.00	.00	21.13	2000.00	299.61	408557.19
63.	Rig Down Cement Tools	1785.00		21.02	1.00	VC-01	525.00	.00	.00	300.61	409082.19
64.	Cement Testing	1785.00		21.07	6.00	VC-01	3150.00	.00	.00	306.61	412232.19
65.	Install Well Head	1785.00		18.01	12.00	VC-01	6300.00	18.02	17000.00	318.61	435532.19
66.	WOC/ Test	1785.00		21.06	18.00	VC-01	9450.00	.00	.00	336.61	444982.19
67.	Change Bit	1785.00		12.01	1.00	VC-01	525.00	12.03	4947.00	337.61	450454.19
68.	Change BHA	1785.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	339.61	452504.19
69.	Trip In	1785.00		14.01	1.50	VC-05	828.00	.00	.00	341.11	453332.19
70.	Drill Cement	1785.00		17.03	.45	VC-02	261.36	.00	.00	341.56	453593.55
71.	Drill	1940.00	155.00	17.01	19.38	VC-02	11140.63	.00	.00	360.93	464734.17
72.	Survey	1940.00		16.01	2.00	VC-01	1050.00	.00	.00	362.93	465784.17
73.	Trip Out	1940.00		14.01	1.50	VC-05	828.00	.00	.00	364.43	466612.17
74.	Change Bit	1940.00		12.01	1.00	VC-01	525.00	12.03	4947.00	365.43	472084.17
75.	Change BHA	1940.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	367.43	474134.17
76.	Trip In	1940.00		14.01	1.50	VC-05	828.00	.00	.00	368.93	474962.17
77.	Drill	2295.00	355.00	17.01	44.38	VC-02	25515.63	.00	.00	413.31	500477.80
78.	Survey	2295.00		16.01	2.00	VC-01	1050.00	.00	.00	415.31	501527.80
79.	Ream	2295.00		17.04	12.50	VC-02	7187.50	.00	.00	427.31	508715.30
80.	Trip Out	2295.00		14.01	1.50	VC-05	828.00	.00	.00	429.31	509543.30
81.	Change Bit	2295.00		12.01	1.00	VC-01	525.00	12.03	4947.00	430.31	515015.30
82.	Change BHA	2295.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	432.31	517065.30
83.	Trip In	2295.00		14.01	1.50	VC-05	828.00	.00	.00	433.81	517893.30
84.	Drill	2463.00	168.00	17.01	21.00	VC-02	12075.00	.00	.00	454.81	529968.30
85.	Survey	2463.00		16.01	2.00	VC-01	1050.00	.00	.00	456.81	531018.30
86.	Trip Out	2463.00		14.01	1.50	VC-05	828.00	.00	.00	458.31	531846.30
87.	Change Bit	2463.00		12.01	1.00	VC-01	525.00	12.03	4947.00	459.31	537318.30
88.	Change BHA	2463.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	461.31	539368.30
89.	Trip In	2463.00		14.01	1.50	VC-05	828.00	.00	.00	462.81	540196.30
90.	Drill	2593.00	130.00	17.02	21.67	VC-04	12025.00	.00	.00	484.48	552221.30
91.	Survey	2593.00		16.01	2.00	VC-01	1050.00	.00	.00	486.48	553271.30
92.	Ream	2593.00		17.05	16.67	VC-02	9583.33	.00	.00	503.14	562854.63
93.	Trip Out	2593.00		14.01	1.50	VC-05	828.00	.00	.00	504.64	563682.63
94.	Condition Mud	2593.00		11.02	3.00	VC-01	1575.00	11.02	500.00	507.64	565757.63
95.	Prepare to Run Casing	2593.00		20.07	24.00	VC-01	12600.00	.00	.00	531.64	578357.63
96.	Rig Up Casing Tools	2593.00		20.01	2.00	VC-01	1050.00	.00	.00	533.64	579407.63
97.	Run 13 3/8 Casing	2593.00		20.04	7.47	VC-05	4123.44	.00	.00	541.11	583531.07
98.	Casing	2593.00		.00	.00	.00	.00	20.12	71761.80	541.11	655292.87
99.	Tools/ Services	2593.00		.00	.00	.00	.00	20.13	7000.00	541.11	662292.87
100.	Rig Down Casing Tools	2593.00		20.02	2.00	VC-01	1050.00	.00	.00	543.11	663342.87
101.	Rig Up Cement Tools	2593.00		21.01	2.00	VC-01	1050.00	.00	.00	545.11	664392.87
102.	Cementing	2593.00		21.03	3.00	VC-01	1575.00	.00	.00	548.11	665967.87
103.	Cement	2593.00		.00	.00	.00	.00	21.14	9200.00	548.11	675167.87
104	Equipment	2593.00		.00	.00	.00	.00	21.15	10000.00	548.11	685167.87
105.	Services	2593.00		.00	.00	.00	.00	21.16	2000.00	548.11	687167.87
106.	Rig Down Cement Tools	2593.00		21.02	1.00	VC-01	525.00	.00	.00	549.11	687692.87
107.	Cement Testing	2593.00		21.07	6.00	VC-01	3150.00	.00	.00	555.11	690842.87
108.	Install Well Head	2593.00		18.01	12.00	VC-01	6300.00	18.03	16000.00	567.11	713142.87
109.	WOC/Test	2593.00		21.06	18.00	VC-01	9450.00	.00	.00	585.11	722592.87
110.	Change Bit	2593.00		12.01	1.00	VC-01	525.00	12.04	8414.00	586.11	731531.87
111.	Change BHA	2593.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	588.11	733581.87

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
112.	Trip In	2593.00		14.01	1.50	VC-05	828.00	.00	.00	589.61	734409.87
113.	Drill Cement	2593.00		17.03	9.09	VC-02	5227.27	.00	.00	598.70	739637.14
114.	Drill	2790.00	197.00	17.02	32.83	VC-04	18222.50	.00	.00	631.54	757859.64
115.	Survey	2790.00		16.01	2.00	VC-01	1050.00	.00	.00	633.54	758909.64
116.	Drill	2999.00	.00	17.02	.00	VC-04	.00	.00	.00	633.54	758909.64
117.	Survey	2999.00		16.01	2.00	VC-01	1050.00	.00	.00	635.54	759959.64
118.	Trip Out	2999.00		14.01	1.50	VC-05	828.00	.00	.00	637.04	760787.64
119.	Change Bit	2999.00		12.01	1.00	VC-01	525.00	12.04	8414.00	638.04	769726.64
120.	Change BHA	2999.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	640.04	771776.64
121.	Trip In	2999.00		14.01	1.50	VC-05	828.00	.00	.00	641.54	772604.64
122.	Drill	3258.00	259.00	17.02	43.17	VC-04	23957.50	.00	.00	684.70	796562.14
123.	Survey	3258.00		16.01	2.00	VC-01	1050.00	.00	.00	686.70	797612.14
124.	Drill	3584.00	326.00	17.02	54.33	VC-04	30155.00	.00	.00	741.04	827767.14
125.	Survey	3584.00		16.01	2.00	VC-01	1050.00	.00	.00	743.04	828817.14
126.	Trip Out	3584.00		14.01	1.50	VC-05	828.00	.00	.00	744.54	829645.14
127.	Change Bit	3584.00		12.01	1.00	VC-01	525.00	12.04	8414.00	745.54	838584.14
128.	Change BHA	3584.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	747.54	840634.14
129.	Trip In	3584.00		14.01	1.50	VC-05	828.00	.00	.00	749.04	841462.14
130.	Drill	3827.00	.00	17.02	.00	VC-04	.00	.00	.00	749.04	841462.14
131.	Survey	3827.00		16.01	2.00	VC-01	1050.00	.00	.00	751.04	842512.14
132.	Drill	3920.00	93.00	17.02	15.50	VC-04	8602.50	.00	.00	766.54	851114.64
133.	Survey	3920.00		16.01	2.00	VC-01	1050.00	.00	.00	768.54	852164.64
134.	Trip Out	3920.00		14.01	1.50	VC-05	828.00	.00	.00	770.04	852992.64
135.	Change Bit	3920.00		12.01	1.00	VC-01	525.00	12.04	8414.00	771.04	861931.64
136.	Change BHA	3920.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	773.04	863981.64
137.	Trip In	3920.00		14.01	1.50	VC-05	828.00	.00	.00	774.54	864609.64
138.	Drill	4223.00	303.00	17.02	50.50	VC-04	28027.50	.00	.00	825.04	892837.14
139.	Survey	4223.00		16.01	2.00	VC-01	1050.00	.00	.00	827.04	893887.14
140.	Trip Out	4223.00		14.01	1.50	VC-05	828.00	.00	.00	828.54	894715.14
141.	Change Bit	4223.00		12.01	1.00	VC-01	525.00	12.04	8414.00	829.54	903654.14
142.	Change BHA	4223.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	831.54	905704.14
143.	Trip In	4223.00		14.01	1.50	VC-05	828.00	.00	.00	833.04	906532.14
144.	Drill	4510.00	287.00	17.02	47.83	VC-04	26547.50	.00	.00	880.87	933079.64
145.	Survey	4510.00		16.01	2.00	VC-01	1050.00	.00	.00	882.87	934129.64
146.	Trip Out	4510.00		14.01	1.50	VC-05	828.00	.00	.00	884.37	934957.64
147.	Change Bit	4510.00		12.01	1.00	VC-01	525.00	12.04	8414.00	885.37	943896.64
148.	Change BHA	4510.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	887.37	945946.64
149.	Trip In	4510.00		14.01	1.50	VC-05	828.00	.00	.00	888.87	946774.64
150.	Drill	4855.00	345.00	17.02	57.50	VC-04	31912.50	.00	.00	946.37	978687.14
151.	Survey	4855.00		16.01	2.00	VC-01	1050.00	.00	.00	948.37	979737.14
152.	Trip Out	4855.00		14.01	1.50	VC-05	828.00	.00	.00	949.87	980565.14
153.	Change Bit	4855.00		12.01	1.00	VC-01	525.00	12.04	8414.00	950.87	989504.14
154.	Change BHA	4855.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	952.87	991554.14
155.	Trip In	4855.00		14.01	1.50	VC-05	828.00	.00	.00	954.37	992382.14
156.	Drill	5012.00	157.00	17.06	26.17	VC-04	14522.50	.00	.00	980.54	1006904.64
157.	Survey	5012.00		16.02	3.00	VC-01	1575.00	.00	.00	983.54	1008479.64
158.	Trip Out	5012.00		14.02	3.50	VC-06	2075.50	.00	.00	987.04	1010555.14
159.	Change Bit	5012.00		12.01	1.00	VC-01	525.00	12.04	8414.00	989.04	1019494.14
160.	Change BHA	5012.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	990.04	1021544.14
161.	Trip In	5012.00		14.02	3.50	VC-06	2075.50	.00	.00	993.54	1023619.64
162.	Drill	5260.00	248.00	17.06	16.53	VC-03	9176.00	.00	.00	1010.07	1032795.64
163.	Trip Out	5260.00		14.02	3.50	VC-06	2075.50	.00	.00	1013.57	1034871.14
164.	Change Bit	5260.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1014.57	1043810.14

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
165.	Change BHA	5260.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1016.57	1045860.14
166.	Trip In	5260.00		14.02	3.50	VC-06	2075.50	.00	.00	1020.07	1047935.64
167.	Drill	5547.00	287.00	17.06	19.13	VC-03	10619.00	.00	.00	1039.20	1058554.64
168.	Survey	5547.00		16.02	3.00	VC-01	1575.00	.00		1042.20	1060129.64
169.	Trip Out	5547.00		14.02	3.50	VC-06	2075.50	.00	.00	1045.70	1062205.14
170.	Change Bit	5547.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1046.70	1071144.14
171.	Change BHA	5547.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1048.70	1073194.14
172.	Trip In	5547.00		14.02	3.50	VC-06	2075.50	.00	.00	1052.20	1075269.64
173.	Drill	5892.00	345.00	17.06	23.00	VC-03	12765.00	.00	.00	1075.20	1088034.64
174.	Survey	5892.00		16.02	3.00	VC-01	1575.00	.00	.00	1078.20	1089609.64
175.	Trip Out	5892.00		14.02	3.50	VC-06	2075.50	.00	.00	1081.70	1091685.14
176.	Change Bit	5892.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1082.70	1100624.14
177.	Change BHA	5892.00		13.01	2.00	VC-01	1050.00	3.02	1000.00	1084.70	1102674.14
178.	Trip In	5892.00		14.02	3.50	VC-06	2075.50	.00	.00	1088.20	1104749.64
179.	Drill	6492.00	600.00	17.06	40.00	VC-03	22200.00	.00	.00	1128.20	1126949.64
180.	Survey	6492.00		16.02	3.00	VC-01	1575.00	.00	.00	1131.20	1128524.64
181.	Trip Out	6492.00		14.02	3.50	VC-06	2075.50	.00	.00	1134.70	1130600.14
182.	Change Bit	6492.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1135.70	1139539.14
183.	Change BHA	6492.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1137.70	1141589.14
184.	Trip In	6492.00		14.02	3.50	VC-06	2075.50	.00	.00	1141.20	1143664.64
185.	Drill	6546.00	54.00	17.06	3.60	VC-03	1998.00	.00	.00	1144.80	1145662.64
186.	Survey	6546.00		16.02	3.00	VC-01	1575.00	.00	.00	1147.80	1147237.64
187.	Ream	6546.00		17.05	16.67	VC-03	9250.00	.00	.00	1164.47	1156487.64
188.	Drill	6619.00	73.00	17.06	4.87	VC-03	2701.00	.00	.00	1169.34	1159188.64
189.	Survey	6619.00		16.02	3.00	VC-01	1575.00	.00	.00	1172.34	1160763.64
190.	Drill	6718.00	99.00	17.06	6.60	VC-03	3663.00	.00	.00	1178.94	1164426.64
191.	Ream	6718.00		17.05	16.67	VC-03	9250.00	.00	.00	1195.60	1173676.64
192.	Trip Out	6718.00		14.02	3.50	VC-06	2075.50	.00	.00	1199.10	1175752.14
193.	Change Bit	6718.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1200.10	1184691.14
194.	Change BHA	6718.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1202.10	1186741.14
195.	Trip In	6718.00		14.02	3.50	VC-06	2075.50	.00	.00	1205.60	1188816.64
196.	Drill	6818.00	100.00	17.06	6.67	VC-03	3700.00	.00	.00	1212.27	1192516.64
197.	Survey	6818.00		16.02	3.00	VC-01	1575.00	.00	.00	1215.27	1194091.64
198.	Drill	6914.00	96.00	17.06	6.40	VC-03	3552.00	.00	.00	1221.67	1197643.64
199.	Survey	6914.00		16.02	3.00	VC-01	1575.00	.00	.00	1224.67	1199218.64
200.	Drill	7003.00	89.00	17.06	5.93	VC-03	3293.00	.00	.00	1230.60	1202511.64
201.	Trip Out	7003.00		14.02	3.50	VC-06	2075.50	.00	.00	1234.10	1204587.14
202.	Change Bit	7003.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1235.10	1213526.14
203.	Change BHA	7003.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1237.10	1215576.14
204.	Trip In	7003.00		14.02	3.50	VC-06	2075.50	.00	.00	1240.60	1217651.64
205.	Drill	7184.00	181.00	17.06	12.07	VC-03	6697.00	.00	.00	1252.67	1224348.64
206.	Survey	7184.00		16.02	3.00	VC-01	1575.00	.00	.00	1255.67	1225923.64
207.	Trip Out	7184.00		14.02	3.50	VC_06	2075.50	.00	.00	1259.17	1227999.14
208.	Change Bit	7184.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1260.17	1236938.14
209.	Change BHA	7184.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1262.17	1238988.14
210.	Trip In	7184.00		14.02	3.50	VC-06	2075.50	.00	.00	1265.67	1241063.64
211.	Drill	7689.00	505.00	17.06	33.67	VC-03	18685.00	.00	.00	1299.34	1259748.64
212.	Trip Out	7689.00		14.02	3.50	VC-06	2075.50	.00	.00	1302.84	1261824.14
213.	Change Bit	7689.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1303.84	1270763.14
214.	Change BHA	7689.00		13.01	2.00	VC-01	1050.00	3.02	1000.00	1305.84	1272813.14
215.	Trip In	7689.00		14.02	3.50	VC-06	2075.50	.00	.00	1309.34	1274888.64
216.	Drill	7743.00	54.00	17.06	3.60	VC-03	1998.00	.00	.00	1312.94	1276886.64
217.	Ream	7743.00		17.05	16.67	VC-03	9250.00	.00	.00	1329.60	1286136.64

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
218.	Survey	7743.00		16.02	3.00	VC-01	1575.00	.00	.00	1332.60	1287711.64
219.	Trip Out	7743.00		14.02	3.50	VC-06	2075.50	.00	.00	1336.10	1289787.14
220.	Change Bit	7743.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1337.10	1298726.14
221.	Change BHA	7743.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1339.10	1300776.14
222.	Trip In	7743.00		14.02	3.50	VC-06	2075.50	.00	.00	1342.60	1302851.64
223.	Drill	8204.00	461.00	17.06	30.73	VC-03	17057.00	.00	.00	1373.34	1319908.64
224.	Trip Out	8204.00		14.02	3.50	VC-06	2075.50	.00	.00	1376.84	1321984.14
225.	Change Bit	8204.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1377.84	1330923.14
226.	Change BHA	8204.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1379.84	1332973.14
227.	Trip In	8204.00		14.02	3.50	VC-06	2075.50	.00	.00	1383.34	1335048.64
228.	Drill	8414.00	210.00	17.06	14.00	VC-03	7770.00	.00	.00	1397.34	1342818.64
229.	Ream	8414.00		17.05	16.67	VC-03	9250.00	.00	.00	1414.00	1352068.64
230.	Survey	8414.00		16.02	3.00	VC-01	1575.00	.00	.00	1417.00	1353643.64
231.	Drill	8545.00	131.00	17.06	8.73	VC-03	4847.00	.00	.00	1425.74	1358490.64
232.	Trip Out	8545.00		14.02	3.50	VC-06	2075.50	.00	.00	1429.24	1360566.14
233.	Change Bit	8545.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1430.24	1369505.14
234.	Change BHA	8545.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1432.24	1371555.14
235.	Trip In	8545.00		14.02	3.50	VC-06	2075.50	.00	.00	1435.74	1373630.64
236.	Drill	8667.00	122.00	17.06	8.13	VC-03	4514.00	.00	.00	1443.87	1378144.64
237.	Survey	8667.00		16.02	3.00	VC-01	1575.00	.00	.00	1446.87	1379719.64
238.	Ream	8667.00		17.05	16.67	VC-03	9250.00	.00	.00	1463.54	1388969.64
239.	Trip Out	8667.00		14.02	3.50	VC-06	2075.50	.00	.00	1467.04	1391045.14
240.	Change Bit	8667.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1468.04	1399984.14
241.	Change BHA	8667.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1470.04	1402034.14
242.	Trip In	8667.00		14.01	3.50	VC-06	2075.50	.00	.00	1473.54	1404109.64
243.	Drill	8975.00	308.00	17.06	20.53	VC-03	11396.00	.00	.00	1494.07	1415505.64
244.	Survey	8975.00		16.02	3.00	VC-01	1575.00	.00	.00	1497.07	1417080.64
245.	Trip Out	8975.00		14.02	3.50	VC-06	2075.50	.00	.00	1500.57	1419156.14
246.	Change Bit	8975.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1501.57	1428095.14
247.	Change BHA	8975.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1503.57	1430145.14
248.	Trip In	8975.00		14.02	3.50	VC-06	2075.50	.00	.00	1507.07	1432220.64
249.	Drill	9188.00	213.00	17.06	14.20	VC-03	7881.00	.00	.00	1521.27	1440101.64
250.	Ream	9188.00		17.05	16.67	VC-03	9250.00	.00	.00	1537.94	1449351.64
251.	Drill	9311.00	123.00	17.06	8.20	VC-03	4551.00	.00	.00	1546.14	1453902.64
252.	Ream	9311.00		17.05	16.67	VC-03	9250.00	.00	.00	1562.80	1463152.64
253.	Survey	9311.00		16.02	3.00	VC-01	1575.00	.00	.00	1565.80	1464727.64
254.	Trip Out	9311.00		14.02	3.50	VC-06	2075.50	.00	.00	1569.30	1466803.14

Conventional Rig
Model 1
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	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
12.	Change Bit	9311.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1570.30	1475742.14
13.	Change BHA	9311.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1572.30	1477792.14
14.	Trip In	9311.00		14.02	3.50	VC-06	2075.50	.00	.00	1575.80	1479867.64
15.	Drill	9467.00	156.00	17.06	10.40	VC-03	5772.00	.00	.00	1586.20	1485639.64
16.	Ream	9467.00		17.05	16.67	VC-03	9250.00	.00	.00	1602.87	1494889.64
17.	Drill	9513.00	46.00	17.06	3.07	VC-03	1702.00	.00	.00	1605.93	1496591.64
18.	Ream	9513.00		17.05	16.67	VC-03	9250.00	.00	.00	1622.60	1505841.64
19.	Drill	9531.00	18.00	17.06	1.20	VC-03	666.00	.00	.00	1623.80	1506507.64
20.	Survey	9531.00		16.02	3.00	VC-01	1575.00	.00	.00	1626.80	1508082.64
21.	Trip Out	9531.00		14.02	3.50	VC-06	2075.50	.00	.00	1630.30	1510158.14
22.	Change Bit	9531.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1631.30	1519097.14
23.	Change BHA	9531.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1633.30	1521147.14
24.	Trip In	9531.00		14.02	3.50	VC-06	2075.50	.00	.00	1636.80	1523222.64
25.	Drill	9616.00	85.00	17.06	5.67	VC-03	3145.00	.00	.00	1642.47	1526367.64
26.	Survey	9616.00		16.02	3.00	VC-01	1575.00	.00	.00	1645.47	1527942.64
27.	Drill	9642.00	26.00	17.06	1.73	VC-03	962.00	.00	.00	1647.20	1528904.64
28.	Survey	9642.00		16.02	3.00	VC-01	1575.00	.00	.00	1650.20	1530479.64
29.	Drill	9718.00	76.00	17.06	5.07	VC-03	2812.00	.00	.00	1655.27	1533291.64
30.	Survey	9718.00		16.02	3.00	VC-01	1575.00	.00	.00	1658.27	1534866.64
31.	Ream	9718.00		17.05	16.67	VC-03	9250.00	.00	.00	1674.93	1544116.64
32.	Trip Out	9718.00		14.02	3.50	VC-06	2075.50	.00	.00	1678.43	1546192.14
33.	Change Bit	9718.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1679.43	1555131.14
34.	Change BHA	9718.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1681.43	1557181.14
35.	Trip In	9718.00		14.02	3.50	VC-06	2075.50	.00	.00	1684.93	1559256.64
36.	Drill	9838.00	120.00	17.06	8.00	VC-03	4440.00	.00	.00	1692.93	1563696.64
37.	Survey	9838.00		16.02	3.00	VC-01	1575.00	.00	.00	1695.93	1565271.64
38.	Drill	9912.00	74.00	17.06	4.93	VC-03	2738.00	.00	.00	1700.87	1568009.64
39.	Survey	9912.00		16.02	3.00	VC-01	1575.00	.00	.00	1703.87	1569584.64
40.	Ream	9912.00		17.05	16.67	VC-03	9250.00	.00	.00	1720.53	1578834.64
41.	Drill	10035.00	123.00	17.06	8.20	VC-03	4551.00	.00	.00	1728.73	1583385.64
42.	Trip Out	10035.00		14.03	7.00	VC-07	4438.00	.00	.00	1735.73	1587823.64
43.	Change Bit	10035.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1736.73	1596762.64
44.	Change BHA	10035.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1738.73	1598812.64
45.	Trip In	10035.00		14.03	7.00	VC-07	4438.00	.00	.00	1745.73	1603250.64
46.	Drill	10067.00	32.00	17.06	2.13	VC-03	1184.00	.00	.00	1747.87	1604434.64
47.	Ream	10067.00		17.05	16.67	VC-03	9250.00	.00	.00	1764.53	1613684.64
48.	Survey	10067.00		16.03	4.00	VC-01	2100.00	.00	.00	1768.53	1615784.64
49.	Drill	10295.00	228.00	17.06	15.20	VC-03	8436.00	.00	.00	1783.73	1624220.64
50.	Ream	10295.00		17.05	16.67	VC-03	9250.00	.00	.00	1800.40	1633470.64
51.	Survey	10295.00		16.03	4.00	VC-01	2100.00	.00	.00	1804.40	1635570.64
52.	Trip Out	10295.00		14.03	7.00	VC-07	4438.00	.00	.00	1811.40	1640008.64
53.	Change Bit	10295.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1812.40	1648947.64
54.	Change BHA	10295.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1814.40	1650997.64
55.	Trip In	10295.00		14.03	7.00	VC-07	4438.00	.00	.00	1821.40	1655435.64
56.	Drill	10433.00	138.00	17.06	9.20	VC-03	5106.00	.00	.00	1830.60	1660541.64
57.	Survey	10433.00		16.03	4.00	VC-01	2100.00	.00	.00	1834.60	1662641.64
58.	Drill	10552.00	119.00	17.06	7.93	VC-03	4403.00	.00	.00	1842.53	1667044.64

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
59.	Trip Out	10552.00		14.03	7.00	VC-07	4438.00	.00	.00	1849.53	1671482.64
60.	Change Bit	10552.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1850.53	1680421.64
61.	Change BHA	10552.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1852.53	1682471.64
62.	Trip In	10552.00		14.03	7.00	VC-07	4438.00	.00	.00	1859.53	1686909.64
63.	Drill	10691.00	139.00	17.02	23.17	VC-04	12857.50	.00	.00	1882.70	1699767.14
64.	Ream	10691.00		17.05	16.67	VC-03	9250.00	.00	.00	1899.37	1709017.14
65.	Survey	10691.00		16.03	4.00	VC-01	2100.00	.00	.00	1903.37	1711117.14
66.	Trip Out	10691.00		14.03	7.00	VC-07	4438.00	.00	.00	1910.37	1715555.14
67.	Change Bit	10691.00		12.01	1.00	VC-01	525.00	12.04	8414.00	1911.37	1724494.14
68.	Change BHA	10691.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	1913.37	1726544.14
69.	Trip In	10691.00		14.03	7.00	VC-07	4438.00	.00	.00	1920.37	1730982.14
70.	Drill	10733.00	42.00	17.02	7.00	VC-04	3885.00	.00	.00	1927.37	1734867.14
71.	Survey	10733.00		16.03	4.00	VC-01	2100.00	.00	.00	1931.37	1736967.14
72.	Ream	10733.00		17.05	16.67	VC-04	9250.00	.00	.00	1948.03	1746217.14
73.	Drill	10876.00	143.00	17.02	23.83	VC-04	13227.50	.00	.00	1971.87	1759444.64
74.	Ream	10876.00		17.05	16.67	VC-04	9250.00	.00	.00	1988.53	1768694.64
75.	Survey	10876.00		16.03	4.00	VC-01	2100.00	.00	.00	1992.53	1770794.64
76.	Trip Out	10876.00		14.03	7.00	VC-07	4438.00	.00		1999.53	1775232.64
77.	Change Bit	10876.00		12.01	1.00	VC-01	525.00	12.04	8414.00	2000.53	1784171.64
78.	Change BHA	10876.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2002.53	1786221.64
79.	Trip In	10876.00		14.03	7.00	VC-07	4438.00	.00	.00	2009.53	1790659.64
80.	Drill	11000.00	124.00	17.02	20.67	VC-04	11470.00	.00	.00	2030.20	1802129.64
81.	Ream	11000.00		17.05	16.67	VC-04	9250.00	.00	.00	2046.87	1811379.64
82.	Survey	11000.00		16.03	4.00	VC-01	2100.00	.00	.00	2050.87	1813479.64
83.	Drill	11097.00	97.00	17.02	16.17	VC-04	8972.50	.00	.00	2067.03	1822452.14
84.	Survey	11097.00		16.03	4.00	VC-01	2100.00	.00	.00	2071.03	1824552.14
85.	Ream	11097.00		17.05	16.67	VC-04	9250.00	.00	.00	2087.70	1833802.14
86.	Trip Out	11097.00		14.03	7.00	VC-07	4438.00	.00	.00	2094.70	1838240.14
87.	Change Bit	11097.00		12.01	1.00	VC-01	525.00	12.04	8414.00	2095.70	1847179.14
88.	Change BHA	11097.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2097.70	1849229.14
89.	Trip In	11097.00		14.03	7.00	VC-07	4438.00	.00	.00	2104.70	1853667.14
90.	Drill	11224.00	127.00	17.02	21.17	VC-04	11747.50	.00	.00	2125.87	1865414.64
91.	Ream	11224.00		17.05	16.67	VC-04	9250.00	.00	.00	2142.53	1874664.64
92.	Survey	11224.00		16.03	4.00	VC-01	2100.00	.00	.00	2146.53	1876764.64
93.	Drill	11289.00	65.00	17.02	10.83	VC-04	6012.50	.00	.00	2157.37	1882777.14
94.	Ream	11289.00		17.05	16.67	VC-04	9250.00	.00	.00	2174.03	1892027.14
95.	Trip Out	11289.00		14.03	7.00	VC-07	4438.00	.00	.00	2181.03	1896465.14
96.	Rig Up Logging Tools	11289.00		15.01	2.00	VC-01	1050.00	.00	.00	2183.03	1897515.14
97.	Trip In	11289.00		15.05	2.00	VC-01	1050.00	.00	.00	2185.03	1898565.14
98.	Log	11289.00		15.06	24.00	VC-01	12600.00	.00	.00	2209.03	1911165.14
99.	Trip Out	11289.00		15.05	2.00	VC-01	1050.00	.00	.00	2211.03	1912215.14
100.	Rig Down Logging Tools	11289.00		15.02	1.00	VC-01	525.00	.00	.00	2212.03	1912740.14
101.	Change Bit	11289.00		12.01	1.00	VC-01	525.00	12.04	8414.00	2213.03	1921679.14
102.	Change BHA	11289.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2215.03	1923729.14
103.	Trip In	11289.00		14.03	7.00	VC-07	4438.00	.00	.00	2222.03	1928167.14
104	Drill	11350.00	61.00	17.02	10.17	VC-04	5642.50	.00	.00	2232.20	1933809.64
105.	Ream	11350.00		17.05	16.67	VC-04	9250.00	.00	.00	2248.87	1943059.64
106.	Survey	11350.00		16.03	4.00	VC-01	2100.00	.00	.00	2252.87	1945159.64
107.	Drill	11616.00	266.00	17.02	44.33	VC-04	24605.00	.00	.00	2297.20	1969764.64
108.	Survey	11616.00		16.03	4.00	VC-01	2100.00	.00	.00	2301.20	1971864.64
109.	Trip Out	11616.00		14.03	7.00	VC-07	4438.00	.00	.00	2308.20	1976302.64
110.	Prepare to Run Casing	11616.00		20.07	24.00	VC-01	12600.00	.00	.00	2332.20	1988902.64
111.	Rig Up Casing Tools	11616.00		20.01	2.00	VC-01	1050.00	.00	.00	2334.20	1989952.64

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (hrs.)	Cum. Cost ($)
112.	Run 9 5/8" Casing	11616.00		20.05	34.71	VC-07	22006.14	.00	.00	2368.91	2011958.78
113.	Casing	11616.00		.00	.00	.00	.00	20.16	315051.10	2368.91	2327009.88
114.	Tools/Services	11616.00		.00	.00	.00	.00	20.17	10000.00	2368.91	2337009.88
115.	Rig Down Casing Tools	11616.00		20.02	2.00	VC-01	1050.00	.00	.00	2370.91	2338059.88
116.	Rig Up Cement Tools	11616.00		21.01	2.00	VC-01	1050.00	.00	.00	2372.91	2339109.88
117.	Cementing	11616.00		21.05	9.00	VC-01	4725.00	.00	.00	2381.91	2343834.88
118.	Cement	11616.00		.00	.00	.00	.00	21.20	950.00	2381.91	2344784.88
119.	Equipment	11616.00		.00	.00	.00	.00	21.21	12000.00	2381.91	2356784.88
120.	Services	11616.00		.00	.00	.00	.00	21.22	4000.00	2381.91	2360784.88
121.	Rig Down Cement Tools	11616.00		21.02	1.00	VC-01	525.00	.00	.00	2382.91	2361309.88
122.	Cement Testing	11616.00		21.07	6.00	VC-01	3150.00	.00	.00	2388.91	2364459.88
123.	Install Well Head	11616.00		18.01	12.00	VC-01	6300.00	18.04	15000.00	2400.91	2385759.88
124.	WOC/Test	11616.00		21.06	18.00	VC-01	9450.00	.00	.00	2418.91	2395209.88
125.	Change Bit	11616.00		12.01	1.00	VC-01	525.00	12.05	4347.00	2419.91	2400081.88
126.	Change BHA	11616.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2421.91	2402131.88
127.	Trip In	11616.00		14.03	7.00	VC-07	4438.00	.00	.00	2428.91	2406569.88
128.	Drill Cement	11616.00		17.03	3.45	VC-02	1986.36	.00	.00	2432.36	2408556.24
129.	Drill	11794.00	178.00	17.02	29.67	VC-04	16465.00	.00	.00	2462.03	2425021.24
130.	Survey	11794.00		16.03	4.00	VC-01	2100.00	.00	.00	2466.03	2427121.24
131.	Drill	11970.00	176.00	17.02	29.33	VC-04	16280.00	.00	.00	2495.36	2443401.24
132.	Survey	11970.00		16.03	4.00	VC-01	2100.00	.00	.00	2499.36	2445501.24
133.	Ream	11970.00		17.05	16.67	VC-04	9250.00	.00	.00	2516.03	2454751.24
134.	Trip Out	11970.00		14.03	7.00	VC-07	147.00	.00	.00	2523.03	2454898.24
135.	Change Bit	11970.00		12.01	1.00	VC-01	525.00	12.05	4347.00	2524.03	2459770.24
136.	Change BHA	11970.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2526.03	2461820.24
137.	Trip In	11970.00		14.03	7.00	VC-07	4438.00	.00	.00	2533.03	2466258.24
138.	Drill	12276.00	306.00	17.02	51.00	VC-04	28305.00	.00	.00	2584.03	2494563.24
139.	Survey	12276.00		16.03	4.00	VC-01	2100.00	.00	.00	2588.03	2496663.24
140.	Drill	12521.00	245.00	17.02	40.83	VC-04	22662.50	.00	.00	2628.86	2519325.74
141.	Survey	12521.00		16.03	4.00	VC-01	2100.00	.00	.00	2632.86	2521425.74
142.	Trip Out	12521.00		14.03	7.00	VC-07	4438.00	.00	.00	2639.86	2525263.74
143.	Change Bit	12521.00		12.01	1.00	VC-01	525.00	12.05	4347.00	2640.86	2530735.74
144.	Change BHA	12521.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2642.86	2532785.74
145.	Trip In	12521.00		14.03	7.00	VC-07	4438.00	.00	.00	2649.86	2537223.74
146.	Drill	12848.00	327.00	17.02	54.50	VC-04	30247.50	.00	.00	2704.36	2567471.24
147.	Survey	12848.00		16.03	4.00	VC-01	2100.00	.00	.00	2708.36	2569571.24
148.	Drill	13012.00	164.00	17.02	27.33	VC-04	15170.00	.00	.00	2735.70	2584741.24
149.	Survey	13012.00		16.03	4.00	VC-01	2100.00	.00	.00	2739.70	2586841.24
150.	Ream	13012.00		17.05	16.67	VC-04	9250.00	.00	.00	2756.36	2596091.24
151.	Trip Out	13012.00		14.03	7.00	VC-07	4438.00	.00	.00	2763.36	2600529.24
152.	Change Bit	13012.00		12.01	1.00	VC-01	525.00	12.05	4347.00	2764.36	2605401.24
153.	Change BHA	13012.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2766.36	2607451.24
154.	Trip In	13012.00		14.03	7.00	VC-07	4438.00	.00	.00	2773.36	2611889.24
155.	Drill	13272.00	260.00	17.02	43.33	VC-04	24050.00	.00	.00	2816.70	2635939.24
156.	Survey	13272.00		16.03	4.00	VC-01	2100.00	.00	.00	2820.70	2638039.24
157.	Drill	13339.00	67.00	17.02	11.17	VC-04	6197.50	.00	.00	2831.86	2644236.74
158.	Survey	13339.00		16.03	4.00	VC-01	2100.00	.00	.00	2835.86	2646336.74
159.	Trip Out	13339.00		14.03	7.00	VC-07	4438.00	.00	.00	2842.86	2650774.74
160.	Change Bit	13339.00		12.01	1.00	VC-01	525.00	12.05	4347.00	2843.86	2655646.74
161.	Change BHA	13339.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2845.86	2657696.74
162.	Trip In	13339.00		14.03	7.00	VC-07	4438.00	.00	.00	2852.86	2662134.74
163.	Drill	13464.00	125.00	17.02	20.83	VC-04	11562.50	.00	.00	2873.70	2673697.24
164.	Survey	13464.00		16.03	4.00	VC-01	2100.00	.00	.00	2877.70	2675797.24

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
165.	Drill	13657.00	153.00	17.02	32.17	VC-04	17852.50	.00	.00	2909.86	2693649.74
166.	Survey	13657.00		16.03	4.00	VC-01	2100.00	.00	.00	2913.86	2695749.74
167.	Ream	13657.00		17.05	16.67	VC-04	9250.00	.00	.00	2930.53	2704999.74
168.	Trip Out	13657.00		14.03	7.00	VC-07	4438.00	.00	.00	2937.53	2709437.74
169.	Change Bit	13657.00		12.01	1.00	VC-01	525.00	12.05	4347.00	2938.53	2714309.74
170.	Change BHA	13657.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	2940.53	2716359.74
171.	Trip In	13657.00		14.03	7.00	VC-07	4438.00	.00	.00	2947.53	2720797.74
172.	Drill	13955.00	298.00	17.02	49.67	VC-04	27565.00	.00	.00	2997.20	2748362.74
173.	Survey	13955.00		16.03	4.00	VC-01	2100.00	.00	.00	3001.20	2750462.74
174.	Drill	14082.00	127.00	17.02	21.17	VC-04	11747.50	.00	.00	3022.36	2762210.24
175.	Survey	14082.00		16.03	4.00	VC-01	2100.00	.00	.00	3026.36	2764310.24
176.	Trip Out	14082.00		14.03	7.00	VC-07	4438.00	.00	.00	3033.36	2768748.24
177.	Change Bit	14082.00		12.01	1.00	VC-01	525.00	12.05	4347.00	3034.36	2773620.24
178.	Change BHA	14082.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	3036.36	2775670.24
179.	Trip In	14082.00		14.03	7.00	VC-07	4438.00	.00	.00	3043.36	2780108.24
180.	Drill	14189.00	107.00	17.02	17.83	VC-04	9897.50	.00	.00	3061.20	2790005.74
181.	Survey	14189.00		16.03	4.00	VC-01	2100.00	.00	.00	3065.20	2792105.74
182.	Drill	14501.00	312.00	17.02	52.00	VC-04	28860.00	.00	.00	3117.20	2820965.74
183.	Survey	14501.00		16.03	4.00	VC-01	2100.00	.00	.00	3121.20	2823065.74
184.	Ream	14501.00		17.05	16.67	VC-04	9250.00	.00	.00	3137.86	2832315.74
185.	Trip Out	14501.00		14.03	7.00	VC-07	4438.00	.00	.00	3144.86	2836753.74
186.	Change Bit	14501.00		12.01	1.00	VC-01	525.00	12.05	4347.00	3145.86	2841625.74
187.	Change BHA	14501.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	3147.86	2843675.74
188.	Trip In	14501.00		14.03	7.00	VC-07	4438.00	.00	.00	3154.86	2848113.74
189.	Drill	14962.00	461.00	17.02	76.83	VC-04	42642.50	.00	.00	3231.70	2890756.24
190.	Survey	14962.00		16.03	4.00	VC-01	2100.00	.00	.00	3235.70	2892856.24
191.	Drill	14966.00	.00	17.02	.00	VC-04	.00	.00	.00	3235.70	2892856.24
192.	Survey	14966.00		16.03	4.00	VC-01	2100.00	.00	.00	3239.70	2894956.24
193.	Trip Out	14966.00		14.03	7.00	VC-07	4438.00	.00	.00	3246.70	2899394.24
194.	Change Bit	14966.00		12.01	1.00	VC-01	525.00	12.05	4347.00	3247.70	2904266.24
195.	Change BHA	14966.00		13.01	2.00	VC-01	1050.00	13.02	1000.00	3249.70	2906316.24
196.	Trip In	14966.00		14.03	7.00	VC-07	4438.00	.00	.00	3256.70	2910754.24
197.	Drill	15273.00	307.00	17.02	51.17	VC-04	28397.50	.00	.00	3307.86	2939151.74
198.	Survey	15273.00		16.03	4.00	VC-01	2100.00	.00	.00	3311.86	2941251.74
199.	Drill	15289.00	16.00	17.02	2.67	VC-04	1480.00	.00	.00	3314.53	2942731.74
200.	Trip Out	15289.00		14.03	7.00	VC-07	4438.00	.00	.00	3321.53	2947169.74
201.	Rig Up Logging Tools	15289.00		15.01	2.00	VC-01	1050.00	.00	.00	3323.53	2948219.74
202.	Trip In	15289.00		15.05	2.00	VC-01	1050.00	.00	.00	3325.53	2949269.74
203.	Log	15289.00		15.06	24.00	VC-01	12600.00	.00	.00	3349.53	2961869.74
204.	Trip Out	15289.00		15.05	2.00	VC-01	1050.00	.00	.00	3351.53	2962919.74
205.	Rig Down Logging Tools	15289.00		15.02	1.00	VC-01	525.00	.00	.00	3352.53	2963444.74
206.											
207.	FIXED CHARGES										
208.	Road & Site							1.00	50000.00	3352.53	3013444.74
209.	Initiation							2.00	15000.00	3352.53	3028444.74
210.	Con. Rig Mobil.							3.01	100000.00	3352.53	3128444.74
211.	Con. Rig Demobil.							3.02	45000.00	3352.53	3173444.74
212.	Fl. Jet Mobil.							3.03	40000.00	3352.53	3213444.74
213.	Fl. Jet Demobil.							3.07	15000.00	3352.53	3228444.74
214.	Water							9.01	6600.00	3352.53	3235044.74
215.	Water Disposal							9.06	6000.00	3352.53	3241044.74

"FLJET1"

Flamejet Drilling
Model No. 1

MODEL 2, CASE I

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
12.	Trip In - New Bit	202.00		14.01	1.50	VC-23	873.00	12.02	12930.00	1.50	13803.00
13.	Drill	604.00	402.00	17.01	50.25	VC-21	30401.25	.00	.00	51.75	44204.25
14.	Survey	604.00		16.01	2.00	VC-20	1110.00	.00	.00	53.75	45314.25
15.	Trip Out	604.00		14.01	1.50	VC-23	873.00	.00	.00	55.25	46187.25
16.	Change Bit	604.00		12.01	1.00	VC-20	555.00	12.02	12930.00	56.25	59672.25
17.	Change BHA	604.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	58.25	61782.25
18.	Trip In	604.00		14.01	1.50	VC-23	873.00	.00	.00	59.75	62655.25
19.	Drill	769.00	165.00	17.01	20.63	VC-21	12478.13	.00	.00	80.38	75133.38
20.	Survey	769.00		16.01	2.00	VC-20	1110.00	.00	.00	82.38	76243.38
21.	Drill	938.00	169.00	17.01	21.13	VC-21	12780.63	.00	.00	103.50	89024.00
22.	Survey	938.00		16.01	2.00	VC-20	1110.00	.00	.00	105.50	90134.00
23.	Trip Out	938.00		14.01	1.50	VC-23	873.00	.00	.00	107.00	91007.00
24.	Change Bit	938.00		12.01	1.00	VC-20	555.00	12.02	12930.00	108.00	104492.00
25.	Change BHA	938.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	110.00	106602.00
26.	Trip In	938.00		14.01	1.50	VC-23	873.00	.00	.00	111.50	107475.00
27.	Ream	938.00		17.04	12.50	VC-21	7562.50	.00	.00	124.00	115037.50
28.	Drill	1052.00	114.00	17.01	14.25	VC-21	8621.25	.00	.00	138.25	123658.75
29.	Survey	1052.00		16.01	2.00	VC-20	1110.00	.00	.00	140.25	124768.75
30.	Drill	1174.00	122.00	17.01	15.25	VC-21	9226.25	.00	.00	155.50	133995.00
31.	Survey	1174.00		16.01	2.00	VC-20	1110.00	.00	.00	157.50	135105.00
32.	Drill	1259.00	85.00	17.01	10.63	VC-21	6428.13	.00	.00	168.13	141533.13
33.	Survey	1259.00		16.01	2.00	VC-20	1110.00	.00	.00	170.13	142643.13
34.	Trip Out	1259.00		14.01	1.50	VC-23	873.00	.00	.00	171.63	143516.13
35.	Change Bit	1259.00		12.01	1.00	VC-20	555.00	12.02	12930.00	172.63	157001.13
36.	Change BHA	1259.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	174.63	159111.13
37.	Trip In	1259.00		14.01	1.50	VC-23	873.00	.00	.00	176.13	159984.13
38.	Drill	1540.00	281.00	17.01	35.13	VC-21	21250.63	.00	.00	211.25	181234.75
39.	Survey	1540.00		16.01	2.00	VC-20	1110.00	.00	.00	213.25	182344.75
40.	Drill	1705.00	165.00	17.01	20.63	VC-21	12478.13	.00	.00	233.88	194822.88
41.	Survey	1705.00		16.01	2.00	VC-20	1110.00	.00	.00	235.88	195932.88
42.	Drill	1729.00	24.00	17.01	3.00	VC-21	1815.00	.00	.00	238.88	197747.88
43.	Survey	1729.00		16.01	2.00	VC-20	1110.00	.00	.00	240.88	198857.88
44.	Trip Out	1729.00		14.01	1.50	VC-23	873.00	.00	.00	242.38	199730.88
45.	Change Bit	1729.00		12.01	1.00	VC-20	555.00	12.02	12930.00	243.38	213215.88
46.	Change BHA	1729.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	245.38	215325.88
47.	Trip In	1729.00		14.01	1.50	VC-23	873.00	.00	.00	246.88	216198.88
48.	Drill	1785.00	56.00	17.01	7.00	VC-21	4235.00	.00	.00	253.88	220433.88
49.	Survey	1785.00		16.01	2.00	VC-20	1110.00	.00	.00	255.88	221543.88
50.	Trip Out	1785.00		14.01	1.50	VC-23	873.00	.00	.00	257.38	222416.88
51.	Condition Mud	1785.00		11.02	3.00	VC-20	1665.00	11.02	100.00	260.38	224181.88
52.	Prepare to Run Casing	1785.00		20.07	24.00	VC-20	13320.00	.00	.00	284.38	237501.88
53.	Rig Up Casing Tools	1785.00		20.01	2.00	VC-20	1110.00	.00	.00	286.38	238611.88
54.	Run 20 inch Casing	1785.00		20.03	6.23	VC-23	3625.86	.00	.00	292.61	242237.74
55.	Casing	1785.00		.00	.00	-	.00	20.10	149822.60	292.61	392060.34
56.	Tools/ Services	1785.00		.00	.00	-	.00	20.11	5000.00	292.61	397060.34
57.	Rig Down Casing Tools	1785.00		20.02	2.00	VC-20	1110.00	.00	.00	294.61	398170.34
58.	Rig Up Cement Tools	1785.00		21.01	2.00	VC-20	1110.00	.00	.00	296.61	399280.34

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
59.	Cementing	1785.00		21.03	3.00	VC-20	1665.00	.00	.00	299.61	408945.34
60.	Cement	1785.00		.00	.00	-	.00	21.11	9200.00	299.61	410145.34
61.	Equipment	1785.00		.00	.00	-	.00	21.12	5000.00	299.61	415145.34
62.	Sevice And Mileage	1785.00		.00	.00	-	.00	21.13	2000.00	299.61	417145.34
63.	Rig Down Cement Tools	1785.00		21.02	1.00	VC-20	555.00	.00	.00	300.61	417700.34
64.	Cement Testing	1785.00		21.07	6.00	VC-20	3330.00	.00	.00	306.61	421030.34
65.	Install Well Head	1785.00		18.01	12.00	VC-20	6660.00	18.02	17000.00	318.61	444690.34
66.	WOC/ Test	1785.00		21.06	18.00	VC-20	9990.00	.00	.00	336.61	454680.34
67.	Change Bit	1785.00		12.01	1.00	VC-20	555.00	12.03	4947.00	337.61	460182.34
68.	Change BHA	1785.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	339.61	462292.34
69.	Trip In	1785.00		14.01	1.50	VC-23	873.00	.00	.00	341.11	463165.34
70.	Drill Cement	1785.00		17.03	.45	VC-21	275.00	.00	.00	341.56	463440.34
71.	Drill	1940.00	155.00	17.01	19.38	VC-21	11721.88	.00	.00	360.93	475162.21
72.	Survey	1940.00		16.01	2.00	VC-20	1110.00	.00	.00	362.93	476272.21
73.	Trip Out	1940.00		14.01	1.50	VC-23	873.00	.00	.00	364.43	477145.21
74.	Change Bit	1940.00		12.01	1.00	VC-20	555.00	12.03	4947.00	365.43	482647.21
75.	Change BHA	1940.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	367.43	484757.21
76.	Trip In	1940.00		14.01	1.50	VC-23	873.00	.00	.00	368.93	485630.21
77.	Drill	2295.00	355.00	17.01	44.38	VC-21	26846.88	.00	.00	413.31	512477.09
78.	Survey	2295.00		16.01	2.00	VC-20	1110.00	.00	.00	415.31	513587.09
79.	Ream	2295.00		17.04	12.50	VC-21	7562.50	.00	.00	427.81	521149.59
80.	Trip Out	2295.00		14.01	1.50	VC-23	873.00	.00	.00	429.31	522022.59
81.	Change Bit	2295.00		12.01	1.00	VC-20	555.00	12.03	4947.00	430.31	527524.59
82.	Change BHA	2295.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	432.31	529634.59
83.	Trip In	2295.00		14.01	1.50	VC-23	873.00	.00	.00	433.81	530507.59
84.	Drill	2463.00	168.00	17.01	21.00	VC-21	12705.00	.00	.00	454.81	543212.59
85.	Survey	2463.00		16.01	2.00	VC-20	1110.00	.00	.00	456.81	544322.59
86.	Trip Out	2463.00		14.01	1.50	VC-23	873.00	.00	.00	458.31	545195.59
87.	Change Bit	2463.00		12.01	1.00	VC-20	555.00	12.03	4947.00	459.31	550697.59
88.	Change BHA	2463.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	461.31	552807.59
89.	Trip In	2463.00		14.01	1.50	VC-23	873.00	.00	.00	462.81	553680.59
90.	Drill	2593.00	130.00	17.02	21.67	VC-22	12675.00	.00	.00	484.48	566355.59
91.	Survey	2593.00		16.01	2.00	VC-20	1110.00	.00	.00	486.48	567465.59
92.	Ream	2593.00		17.05	16.67	VC-22	9750.00	.00	.00	503.14	577215.59
93.	Trip Out	2593.00		14.01	1.50	VC-23	873.00	.00	.00	504.64	578088.59
94.	Condition Mud	2593.00		11.02	3.00	VC-20	1665.00	11.02	500.00	507.64	580253.59
95.	Prepare to Run Casing	2593.00		20.07	24.00	VC-20	13320.00	.00	.00	531.64	593573.59
96.	Rig Up Casing Tools	2593.00		20.01	2.00	VC-20	1110.00	.00	.00	533.64	594683.59
97.	Run 13 3/8 Casing	2593.00		20.04	7.47	VC-23	4347.54	.00	.00	541.11	599031.13
98.	Casing	2593.00		.00	.00	-	.00	20.12	71761.80	541.11	670792.93
99.	Tools/ Services	2593.00		.00	.00	-	.00	20.13	7000.00	541.11	677792.93
100.	Rig Down Casing Tools	2593.00		20.02	2.00	VC-20	1110.00	.00	.00	543.11	678902.93
101.	Rig Up Cement Tools	2593.00		21.01	2.00	VC-20	1110.00	.00	.00	545.11	680012.93
102.	Cementing	2593.00		21.03	3.00	VC-20	1665.00	.00	.00	548.11	681677.93
103.	Cement	2593.00		.00	.00	-	.00	21.14	9200.00	548.11	690877.93
104	Equipment	2593.00		.00	.00	-	.00	21.15	10000.00	548.11	700877.93
105.	Services	2593.00		.00	.00	-	.00	21.16	2000.00	548.11	702877.93
106.	Rig Down Cement Tools	2593.00		21.02	1.00	VC-20	555.00	.00	.00	549.11	703432.93
107.	Cement Testing	2593.00		21.07	6.00	VC-20	3330.00	.00	.00	555.11	706762.93
108.	Install Well Head	2593.00		18.01	12.00	VC-20	6660.00	18.03	16000.00	567.11	729422.93
109.	WOC/Test	2593.00		21.06	18.00	VC-20	9990.00	.00	.00	585.11	739412.93
110.	Change Bit	2593.00		12.01	1.00	VC-20	555.00	12.04	4947.00	586.11	744914.93
111.	Change BHA	2593.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	588.11	747024.93

	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
112.	Trip In	2593.00		14.01	1.50	VC-23	873.00	.00	.00	589.61	747897.93
113.	Drill Cement	2593.00		17.03	9.09	VC-21	5500.00	.00	.00	598.70	753397.93
114.	Trip Out	2593.00		14.01	1.50	VC-23	873.00	.00	.00	600.20	754270.93
115.	Convert to Fl. Jet Drig.	2593.00		4.13	4.00	VC-10	1988.00	.00	.00	604.20	756258.93
116.	Trip In	2593.00		14.04	1.50	VC-13	775.50	.00	.00	605.70	757034.43
117.	Flame Jet Drill	3793.00	1200.00	17.08	24.00	VC-12	16320.00	.00	.00	629.70	773354.43
118.	Trip Out	3793.00		14.04	1.50	VC-13	775.50	.00	.00	631.20	774129.93
119.	Fl. Jet Maintenance	3793.00		4.17	2.00	VC-10	994.00	4.18	200.00	633.20	775323.93
120.	Trip In	3793.00		14.04	1.50	VC-13	775.50	.00	.00	634.70	776099.43
121.	Flame Jet Drill	4993.00	1200.00	17.08	24.00	VC-12	16320.00	.00	.00	658.70	792419.43
122.	Trip Out	4993.00		14.04	1.50	VC-13	775.50	.00	.00	660.20	793194.93
123.	Fl. Jet Maintenance	4993.00		4.17	2.00	VC-10	994.00	4.18	200.00	662.20	794388.93
124.	Trip In	4993.00		14.04	1.50	VC-13	775.50	.00	.00	663.70	795164.43
125.	Flame Jet Drill	6673.00	1680.00	17.09	24.00	VC-12	16320.00	.00	.00	687.70	811484.43
126.	Trip Out	6673.00		14.05	3.50	VC-14	1953.00	.00	.00	691.20	813437.43
127.	Fl. Jet Maintenance	6673.00		4.17	2.00	VC-10	994.00	4.18	200.00	693.20	814631.43
128.	Trip In	6673.00		14.05	3.50	VC-14	1953.00	.00	.00	696.70	816584.43
129.	Flame Jet Drill	8353.00	1680.00	17.09	24.00	VC-12	16320.00	.00	.00	720.70	832904.43
130.	Trip Out	8353.00		14.05	3.50	VC-14	1953.00	.00	.00	724.20	834857.43
131.	Fl. Jet Maintenance	8353.00		4.17	2.00	VC-10	994.00	4.18	200.00	726.20	836051.43
132.	Trip In	8353.00		14.05	3.50	VC-14	1953.00	.00	.00	729.70	838004.43
133.	Flame Jet Drill	9570.00	1217.00	17.09	17.39	VC-12	11822.29	.00	.00	747.09	849826.71
134.	Trip Out	9570.00		14.05	3.50	VC-14	1953.00	.00	.00	750.59	851779.71
135.	Fl. Jet Maintenance	9570.00		4.17	2.00	VC-10	994.00	4.18	200.00	752.59	852973.71
136.	Change BHA	9570.00		4.19	2.00	VC-10	994.00	.00	.00	754.59	853967.71
137.	Trip In	9570.00		14.05	3.50	VC-14	1953.00	.00	.00	758.09	855920.71
138.	Flame Jet Drill	11250.00	1680.00	17.09	24.00	VC-12	16320.00	.00	.00	782.09	872240.71
139.	Trip Out	11250.00		14.06	7.00	VC-15	4193.00	.00	.00	789.09	876433.71
140.	Fl. Jet Maintenance	11250.00		4.17	2.00	VC-10	994.00	4.18	200.00	791.09	877627.71
141.	Trip In	11250.00		14.06	7.00	VC-15	4193.00	.00	.00	798.09	881820.71
142.	Flame Jet Drill	11616.00	366.00	17.10	4.07	VC-12	2765.33	.00	.00	802.16	884586.04
143.	Trip Out	11616.00		14.06	7.00	VC-15	4193.00	.00	.00	809.16	888779.04
144.	Rig Up Logging Tools	11616.00		15.01	2.00	VC-20	1110.00	.00	.00	811.16	889889.04
145.	Trip In	11616.00		15.05	2.00	VC-20	1110.00	.00	.00	813.16	890999.04
146.	Log	11616.00		15.06	24.00	VC-20	13320.00	.00	.00	837.16	904319.04
147.	Trip Out	11616.00		15.05	2.00	VC-20	1110.00	.00	.00	839.16	905429.04
148.	Rig Down Logging Tools	11616.00		15.02	1.00	VC-20	555.00	.00	.00	840.16	905984.04
149.	Prepare to Run Casing	11616.00		20.07	24.00	VC-20	13320.00	.00	.00	864.16	919304.04
150.	Rig Up Casing Tools	11616.00		20.01	2.00	VC-20	1110.00	.00	.00	866.16	920414.04
151.	Run 9 5/8 Casing	11616.00		20.05	34.71	VC-25	23047.44	.00	.00	900.87	943461.48
152.	Casing	11616.00		.00	.00	-	.00	20.16	315051.10	900.87	1258512.58
153.	Tools/ Services	11616.00		.00	.00	-	.00	20.17	10000.00	900.87	1268512.58
154.	Rig Down Casing Tools	11616.00		20.02	2.00	VC-20	1110.00	.00	.00	902.87	1269622.58
155.	Rig Up Cement Tools	11616.00		21.01	2.00	VC-20	1110.00	.00	.00	904.87	1270732.58
156.	Cementing	11616.00		21.05	9.00	VC-20	4995.00	.00	.00	913.87	1275727.58
157.	Cement	11616.00		.00	.00	-	.00	21.20	950.00	913.87	1276677.58
158.	Equipment	11616.00		.00	.00	-	.00	21.21	12000.00	913.87	1288677.58
159.	Services	11616.00		.00	.00	-	.00	21.22	4000.00	913.87	1292677.58
160.	Rig Down Cement Tools	11616.00		21.02	1.00	VC-20	555.00	.00	.00	914.87	1293232.58
161.	Cement Testing	11616.00		21.07	6.00	VC-20	3330.00	.00	.00	920.87	1296562.58
162.	Install Well Head	11616.00		18.01	12.00	VC-20	6660.00	18.04	15000.00	932.87	1318222.58
163.	WOC/Test	11616.00		21.06	18.00	VC-20	9990.00	.00	.00	950.87	1328212.58
164.	Change Bit	11616.00		12.01	1.00	VC-20	555.00	12.02	12930.00	951.87	1341697.58

#	Activity	Depth (Ft.)	Depth Drilled (Ft.)	Operation Time Category	Operation Time (Hrs.)	Variable Cost Category	Variable Cost ($)	Direct Cost Category	Direct Cost ($)	Cum. Time (Hrs.)	Cum. Cost ($)
165.	Change BHA	11616.00		13.01	2.00	VC-20	1110.00	13.02	1000.00	953.87	1343807.58
166.	Trip In	11616.00		14.03	7.00	VC-25	4648.00	.00	.00	960.87	1348455.58
167.	Drill Cement	11616.00		17.03	3.45	VC-21	2090.00	.00	.00	964.32	1350545.58
168.	Trip Out	11616.00		14.03	7.00	VC-25	4648.00	.00	.00	971.32	1355193.58
169.	Convert to Fl. Jet	11616.00		4.13	4.00	VC-10	1988.00	.00	.00	975.32	1357181.58
170.	Trip In	11616.00		14.06	7.00	VC-15	4193.00	.00	.00	982.32	1361374.58
171.	Flame Jet Drill	13776.00	2160.00	17.10	24.00	VC-12	16320.00	.00	.00	1006.32	1377694.58
172.	Trip Out	13776.00		14.06	7.00	VC-15	4193.00	.00	.00	1013.32	1381887.58
173.	Fl. Jet Maintenance	13776.00		4.17	2.00	VC-10	994.00	4.18	200.00	1015.32	1383081.58
174.	Trip In	13776.00		14.06	7.00	VC-15	4193.00	.00	.00	1022.32	1387274.58
175.	Flame Jet Drill	15289.00	1513.00	17.10	16.81	VC-12	11431.56	.00	.00	1039.13	1398706.14
176.	Trip Out	15289.00		14.06	7.00	VC-15	4193.00	.00	.00	1046.13	1402899.14
177.	Rig Up Logging	15289.00		15.01	2.00	VC-20	1110.00	.00	.00	1048.13	1404009.14
178.	Trip In	15289.00		15.05	2.00	VC-20	1110.00	.00	.00	1050.13	1405119.14
179.	Log	15289.00		15.06	24.00	VC-20	13320.00	.00	.00	1074.13	1418439.14
180.	Trip Out	15289.00		15.05	2.00	VC-20	1110.00	.00	.00	1076.13	1419549.14
181.	Rig Down Logging Tools	15289.00		15.02	1.00	VC-20	555.00	.00	.00	1077.13	1420104.14
182.											
183.	Fixed Charges										
184.	Road & Site							1.00	50000.00	1077.13	1470104.14
185.	Initiation							2.00	15000.00	1077.13	1485104.14
186.	Con. Rig Mobil.							3.01	100000.00	1077.13	1585104.14
187.	Con. Rig Demobil.							3.02	45000.00	1077.13	1630104.14
188.	Flame Jet Mobil.							3.03	10000.00	1077.13	1640104.14
189.	Flame Jet Demobil.							3.07	5000.00	1077.13	1645104.14
190.	Water							9.01	6600.00	1077.13	1651704.14
191.	Water Disposal							9.06	6000.00	1077.13	1657704.14